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ORIGINAL ARTICLES.

The Metamorphic Rocks of Gunong Terendum, Kinta Valley, Federated Malay States.

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In a previous paper in this Magazine, as well as in an official report to the Government of the Federated Malay States and in a paper in the *Mining Magazine*, I have discussed in some detail the geological relations of the pregranitic sedimentary rocks of the Kinta Valley, in the State of Perak, F.M.S.[1] The relations of the mainly calcareous Raub Series of Permo-Carboniferous age and the rocks generally known locally and colloquially as the "Schist Series" (Triassic and perhaps Rhaetic), formed one of the principal subjects on which I was requested to report to the Government. My conclusions were, I think, sufficiently clearly expressed in the publications quoted, and it is unnecessary to repeat here the arguments and field evidence which led me to those conclusions.

In the course of the above-named investigations I examined, in company with Mr. E. S. Willbourn, of the F.M.S. Geological Survey, a locality where the field relations of the limestone and some schists were shown with special clearness, as also the metamorphism induced in them by the intrusion of the granite of the Main Range: a large number of specimens were collected and sliced, partly by the Malay Staff of the Geological Survey at Batu Gajah, and partly after my return home. At a later date Mr. Willbourn sent me further specimens and notes. The following paper is in the main a petrographical description of these various specimens, which it is believed present some points of interest.

The locality in question is the eastern face of Gunong Terendum, a typical limestone hill about 1,500 feet high, just north of Pulai on the east side of the Kinta Valley, some 6 miles E.S.E. of Ipoh. This eastern face is extraordinarily steep, overhanging in places,

[1] Rastall, "The Limestone of the Kinta Valley," Geol. Mag., lxiv, 1927, 410. "The Geology of the Kinta Valley," *Mining Mag.*, xxxvi, 1927, 329.

and the country is by no means easy to explore, owing to jungle and other things. The best way to reach the place is to go to Pulai, to which point there is an excellent motor road, then take the road past the scheelite mine, and about a quarter of a mile beyond the mine turn sharply to the left, up the narrow valley between a small isolated limestone hill and Gunong Terendum itself. Up this valley there is a rough buffalo track for a considerable distance. The locality can also be reached from Ampang, but this route is much longer, involves wading through the Sungei Raia, and is not to be recommended.

The field relations of the limestone and schist at this locality have been rather fully discussed in the paper first quoted. The main points are that the limestone-schist contact is approximately vertical; that both rocks are considerably metamorphosed; and that both are penetrated by veins of granite: the actual contact with the main mass of the granite bathylith is not seen, and it is not known whether there is any faulting between the sediments and the igneous rock.

There is an extensive exposure, largely masked by jungle, of the limestone-schist contact, the schist in one place forming something like 100 feet of the lowest part of the cliff: here and there are to be seen splashes, as it were, of the dark schist adhering to the overhanging face of the white limestone, so that the generally very steep or vertical character of the junction is unmistakable. Naturally there are also loose blocks of the schistose rocks scattered about in the jungle, in the narrow valley between the limestone cliff and the granite mountains to the east.

As will appear sufficiently from the earlier description, the foliation of the rocks, here called for convenience the Schist Series, is essentially vertical, with an infinity of minor corrugations. It is also quite clear that this foliation is in reality the bedding of a stratified series, consisting of sediments of varying character: siliceous, argillaceous, and to some extent calcareous. Whether this variable sedimentary series was or was not originally conformable with the limestone is a point of much interest and difficulty which is still undecided: for our present purpose it is immaterial. At Gunong Terendum, though not everywhere, the contact is perfectly sharp and definite, and there is little or no indication of any gradual transition. The demarcation of the two series is rendered specially easy by the sharp contrast between the pure white limestone and the general dark grey tint of the schists, so that the boundaries can be seen even in the inaccessible portions of the overhanging cliffs.

A small diagram illustrating the relations of the two formations is here reproduced from the former paper.

I have a number of photographs of the locality, but as they were all taken in thick jungle in a very poor light, they are not good enough for reproduction.

Granite Veins.

It has already been mentioned that the altered sediments are penetrated by granite veins near the contact. These are usually quite small, the widest actually observed being about 1 foot thick.[1] It is unnecessary to give a long description of these veins, but one or two points are worthy of note and have some bearing on the question of the metamorphism. In the first place the texture is decidedly coarse for such small veins, the felspars running up to half an inch in length; secondly, the rock is obviously very high

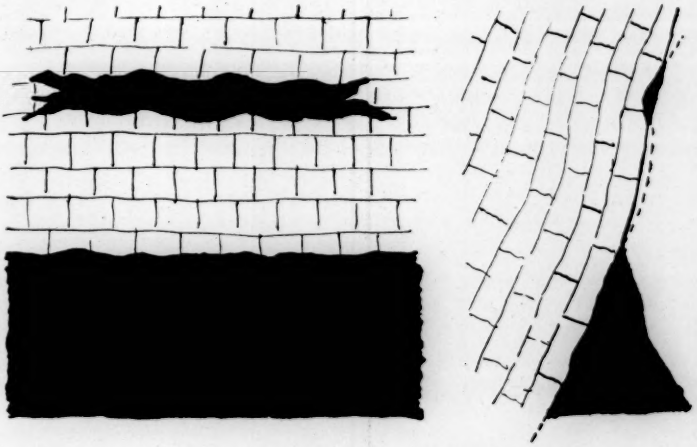

Fig. 1.—Front view (left) and section (right) of limestone-schist contact at Gunong Terendum.

Note.—In the left-hand figure, the stippling to indicate limestone is purely diagrammatic, since the surface shown is in reality one bedding plane. In the right-hand figure the stippling does represent the actual bedding.

in silica; thirdly, pneumatolytic minerals are present, especially topaz.

The rock of these veins, of which 6859 may be taken as a type, consists mainly of abundant quartz in large crystals with crenulated edges and strain shadows and some granulation; and numerous kinds of felspar, including different types of perthite (the most abundant), and a small amount of an albite-rich plagioclase (extinction on the average nearly straight). Some hand-specimens show a good deal of muscovite in very small flakes: this may be secondary (greisening), but the slices available show only very small quantities of either muscovite or biotite; there is, however, a lot of topaz. In one specimen (R.20.4), there is a good deal of

[1] Inche Mayah bin Latib saw a granite dyke 4 feet wide somewhat further to the north; of this he gave me a rough sketch.

a rather unusual type of tourmaline, of a clear blue colour, which seems to be derived from biotite. There are a few grains of cassiterite in all specimens.

The object of this brief description is merely to show that there is evidence of well-marked pneumatolytic phenomena accompanying the intrusion of the granite, even in such small veins, and that therefore we should expect to find minerals characteristic of metasomatic action in the sediments also. From the abundance of perthite it would appear that the magma was rich in soda: at any rate this is clearly an alkali-granite.

The Schists.

The material available for this description consists of about thirty microscope slides, partly from material collected by myself and partly collected and sent to me at a later date by Mr. Willbourn, together with some further notes as to the occurrence of the same. It is not possible under the circumstances to do more than describe the petrography of the slices and of the accompanying hand-specimens when such are available: so far as I am aware all the specimens form part of what is obviously a continuous sedimentary series: the secondary pressure-foliation is on the whole roughly parallel to the original bedding, although there has been a good deal of crumpling on a small scale. One slice only was made from a loose block not in situ, but, owing to its very large size, it could not have travelled far. In these circumstances the order in which the slides are described is of no importance, and as a matter of practical convenience, those collected by myself are taken first: they bear numbers of the type R.20.3, which refer to my own notebooks.

R.20.1.—Of this rock there are two slices available, which differ slightly in character, owing to the fact that the larger one includes a layer differing in original composition from the rest, but half of the larger one is precisely similar to the whole of the other.

The rock is dark brown in colour and shows very strongly marked foliation and microscopic folding: some flattened lenticular structures may be crushed quartz pebbles. The light bands consist almost entirely of finely granular quartz, with occasional streaks and patches of black material, probably carbon. The different bands of quartz vary much in texture, some being very finely granular indeed: I have not been able to establish the existence of any felspar, although I feel little doubt that there is some in certain bands. The dark bands consist mainly of brown biotite, mixed up with carbon and a considerable amount of dirty green tourmaline, which is rather difficult to make out except under a high power: it looks as if it was formed from biotite.

There are also a few bands, of fairly coarse texture, only seen in the larger slice, as before noticed, which consist mainly of quartz

and a colourless pyroxene. The last named mineral occurs in many other slices of this collection in much better development, so a description of it may be deferred.

This rock clearly represents an original finely-laminated sediment, with alternate layers of sand and silt, which has been subjected to intense crushing, as well as thermal metamorphism. Possibly it also contained a number of quartz pebbles, but on the material available I do not feel able to decide whether all the lenticular structures may not be explained by folding.

The rock may be called a biotite-tourmaline-quartz-schist.

R.20.3*a*.—A somewhat schistose rock, with veins of calcite. The structure is very confused and it is probably a crush-breccia. Parts of it consist of the usual type of granular quartz-pyroxene-schist, to be described from better specimens shortly : other patches may be bits of a crushed granite vein. There is some prehnite in the pyroxenitic portions : see R. 20.6. below.

R.20.3*b*.—This is an example of the highly quartzose variety of the quartz-pyroxene-schist. It is strongly banded, some bands consisting almost entirely of quartz with a little felspar, while other bands contain a good deal of pyroxene. Cassiterite is fairly common in elongated crystals arranged parallel to the schistosity and there is a good deal of fresh pyrrhotite.

R.20.3*c*.—This is the only specimen here described that was not in place. It was collected as being a specially fine example of the type of structure displayed by the schists.

The banding is very strongly marked and the slice shows a particularly fine example of strain-slip on a small scale with a sharp fold passing into a discontinuity. Essentially the rock is a quartz-mica-pyroxene-schist, with much carbon and some sulphide. The structure is made specially conspicuous by the strong colour-differentiation into black, brown, green and colourless bands. Both the brown and the green minerals are micas. There is not much pyroxene.

R.20.6.—This interesting rock has a very complex composition. It consists of garnet, pyroxene, prehnite, quartz, a very little felspar and calcite. There is a slight indication of a banded structure. The garnet is colourless and not birefringent or only very slightly so : it is rarely idiomorphic, but usually shows very irregular forms : it is very abundant in certain bands. The pyroxene shows the usual characters. Prehnite is fairly abundant in certain bands ; it is easily distinguished from the pyroxene by its much lower refractive index, and traces of the peculiar twinning can be made out here and there. What little felspar there is appears to be plagioclase. This rock is evidently related to R. 20.3*a*, and is formed from an impure calcareous band or possibly by reaction between

a calcareous and a muddy rock: there must be a good deal of Al_2O_3 in it.

I have to thank Dr. Tilley and Dr. F. C. Phillips for determining the prehnite, a mineral with which I had little previous acquaintance.

R.20.7.—This slice is rather difficult to make out owing to the presence of much black material, probably carbon, as well as red iron oxide. It appears to consist mostly of quartz, pyroxene, chlorite, garnet, with a little amphibole, chlorite and cassiterite, and perhaps some felspar. There may be other minerals as well, but the slice is hardly worth spending much time over. It is a slight variant of the usual quartz-pyroxene schist, but is not very schistose. The hand-specimen shows large lenticles of quartz, strongly suggestive of pebbles.

All the foregoing were collected by myself. Those that follow were sent to me by Mr. Willbourn, having been collected by him in December, 1927. The numbers refer to the collection of the Geological Survey of the F.M.S.

6852*c*.—From a big block near the foot of the cliff. A dark grey strongly banded rock consisting of contorted layers of nearly pure granular quartz, alternating with dark bands, which are mainly biotite and brown or dirty green tourmaline, with some pale green amphibole, often transverse to the foliation. There is also some pyrrhotite, a little cassiterite, and a good deal of finely divided carbon. There is, of course, some quartz in the dark bands. The hand specimen shows a lot of pyrrhotite. It is a quartz-biotite-tourmaline-schist.

6852*d*.—This differs from the last mainly in the absence of tourmaline and in the presence of more amphibole in the quartzose bands. This amphibole is very pale green and only faintly pleochroic. Some, if not all, of it may be secondary after pyroxene. Also there is rather more cassiterite, which in some instances is unusually pale in colour (pleochroism rose-pink to pale green).

6853*b* and 6853*d* are from specimens in situ in the cliff. They are obviously identical with my R. 20.1, already described, and with the large block 6852.

It is a strongly banded, fine-grained rock with alternate layers, averaging 1 mm., of dark grey or nearly black and whitish colours. Joint faces are much slickensided. This particular specimen is not contorted, but intensely sheared, with the same flattened lenticles. One such, of coarse quartz, is half an inch thick; other smaller lenticles of yellowish quartz strongly suggest quartz pebbles.

6852*b* consists of quartz, biotite, sericitic white mica and carbon in very clean-cut bands of varying composition: some are nearly pure quartz, with or without carbon; others with a large proportion of biotite. I have not been able to identify felspar, though some

may be present. The two micas are mostly in the same bands, though there is a little sericite in the quartzose bands.

The biotite is bright foxy-red, with very strong pleochroism (colourless one way) and a few rather ill-defined haloes. No amphibole, pyroxene or tourmaline were found in this slice, but in 6853*d*, which is cut parallel to the foliation and is rather disfigured by yellow staining, numerous prisms of dirty green tourmaline can be made out.

In some of the more micaceous bands of 6853*b*, there are structures suggestive of micaceous pseudomorphs after andalusite or cordierite, but it is impossible to be sure of their real nature.

6854.—Schist in situ from the large exposure near a wild-goat trap. This is an intensely crushed and contorted rock with lenticles of quartz up to $\frac{1}{4}$ inch across. The whole rock is much stained and difficult to make out. The chief constituents are quartz, chloritized mica and large garnets, all very irregularly distributed, the garnets being confined to certain bands. The texture and structure vary very rapidly from place to place.

The quartzose bands and lenticles vary much in size of component grains; some being coarse, others very finely granular. There may be some felspar in these bands. The mica is of a bright orange-brown colour, and nearly always much chloritized and stained, so that its pleochroism and birefringence are largely masked. Mr. Willbourn found hornblende in slices with the same number, but I have not been able to convince myself of the presence of this mineral. The garnets are either very faint pink or colourless: they are much cracked and show small black inclusions, but there is no trace of birefringence. Among less common constituents I have been able to make out a little tourmaline and a few grains of cassiterite.

6855.—Near the same locality as the foregoing, but a little further west. Mr. Willbourn states that the specimens were collected from bands of schist 1 inch thick, in the limestone, 1 foot above the contact. They appear to have been sheared off from the schist below and included in the limestone. The best hand-specimen consists as to one-half of crystalline limestone, rather coarse, whereas the other half looks like a breccia of schist and finer-grained limestone. This is confirmed by the slice 6855*a*, which shows angular fragments, mostly composed of a much chloritized mica, stained yellow and embedded in a rather finely granular limestone matrix. Another slice prepared later shows large flakes of a highly ferriferous bright orange-red chlorite in granular calcite.[1] In both slices there is a certain amount of a ferriferous carbonate, chalybite or ankerite, in patches.

[1] It is not known how much of the "calcite" here described is really dolomite. Most of it shows polysynthetic twin lamellae to some extent.

The whole rock shows clear indications of intense crushing and brecciation.

6856.—Of this only one small hand specimen is available: it was collected from the main mass of schist below the limestone at 6855. It is a dark grey, finely granular and compact, slightly spotty rock, showing no particular structure to the naked eye, though in the slices banding and contortion can be easily seen. Here again there are small patches of granular quartz, which may be pebbles. There is in the other parts a good deal of finely divided black material, most likely carbon.

The texture of the dark part of the rock is very fine. It consists chiefly of quartz and colourless pyroxene. Most of the last named is in very minute shapeless grains, but here and there large crystals with cleavage allowed the optical properties to be determined. The birefringence is high and the extinction angle up to 40°. It may be called diopside. In 6856*c* there is a little very pale greenish amphibole, which is certainly secondary after pyroxene, as suggested by Mr. Willbourn. There is a little pyrite and pyrrhotite, as well as a good many minute grains of cassiterite.

6857.—A few chains W.N.W. from the goat-trap. Much like the last in general appearance, but more schistose and with more quartzose lenticles and bands. However, the two available slices bearing this number differ to some extent.

Slice 6857*b* is a strongly banded and sheared rock, mostly very dark in colour, but with a large clear irregular patch consisting chiefly of quartz: part of this is probably a quartz vein, but the other part contains a little pale green amphibole in addition to quartz. The dark part of the slice is of very fine texture, with a great deal of black material. The principal minerals are quartz and biotite, the latter in very small flakes, and a dirty green, very imperfectly developed tourmaline, which is certainly derived from the biotite. Many of the tourmaline crystals are full of black inclusions, probably the excess iron oxide of the biotite, which could not be taken up by the tourmaline molecule. This mineral can really only be made out with a high-power objective and condenser.

Slice 6857*c* consists mainly of quartz, with a little pale green amphibole, some carbon and a good deal of pyrrhotite. It is very like the clearer part of 6857*b*.

The minerals and structures of these two slices do not require detailed description. The darker part of the rock is evidently closely allied to R. 20.1, a quartz-mica-tourmaline-schist.

6858.—This locality is 5 or 6 chains W.N.W. from the goat-trap, and about 10 chains E.S.E. from the spot where there is a turn to N.N.E. in the line of cliffs. There is a vertical granite vein, 1 foot wide, intrusive in the schist (6859, see page 195). There are altogether six slices bearing the number 6858, which differ a good

deal among themselves. The only hand-specimen of sediment available is a banded crystalline limestone of a pale yellowish colour, which in places shows some remarkably interesting minerals, to be described later.

Slice 6858*d* is identical with R. 20.3*c*, already described, though rather less strongly contorted. 6858*b* belongs to the same type structurally and mineralogically, the chief difference being the presence of a pale green amphibole instead of pyroxene: it may be derived from the pyroxene.

There are two slices bearing the plain number 6858, without any qualifying letter. These differ entirely in character and need separate description, although they were cut from the same small block of rock, which is rather finely granular in texture, slightly banded and pale grey or nearly white. In one place, however, is a coarsely crystalline patch from which one of the slices was cut.

Taking first the fine-grained type, of which a large slice was cut by Jacobsen, of Oslo, a difficulty arises in describing it, because it consists of numerous thin bands a few mm. wide, nearly all of which differ in some way. In general terms, however, most of the rock consists of felspar, pyroxene, garnet, and carbonates in varying proportions; there seems to be a little fluorite as well in places, but this is not always easy to distinguish from garnet in small grains.

Another slice cut at Cambridge from the same block, is of great interest, as it is a particularly fine example of a garnet-idocrase rock. There is a strong resemblance to the rock figured by Mr. Harker from Shap, the chief difference being that in this case the matrix consists of crystalline calcite in large crystals. The crystals of garnet and idocrase in one small patch in the hand-specimen from which this slice was cut are several mm. in diameter.

The garnet is pale yellow-brown in the hand-specimen, colourless in thin section, forming perfect rhombic dodecahedra with sharp angles: it is distinctly birefringent, in sectors, as in the Shap rock, and always idiomorphic towards the other minerals, except the small scattered grains of pyroxene, to be mentioned presently. The idocrase is colourless in thin section, in large rectangular crystals which often more or less enclose the garnets. The calcite in very large crystals with the usual lamellar twinning encloses all the other minerals poecilitically. Enclosed in all the other minerals to a greater or less extent and more especially in the calcite are innumerable tiny grains of a colourless pyroxene with strong birefringence, just as at Shap.

6858*a* and 6858*f* are other and not very good examples of the felspar-pyroxene-garnet-carbonate rock: in one of them there is a good deal of idocrase, in fairly large crystals. These do not require separate description.

It is clear that there are included in this collection from Gunong Terendum three principal rock-types, as follows:—

(*a*) quartz-biotite-tourmaline-schist, intensely crushed and perhaps containing flattened pebbles.
(*b*) quartz-pyroxene-schist, much contorted.
(*c*) Felspar-garnet-pyroxene-idocrase-carbonate rocks, without much sign of crushing.

These three types represent a series of mixed sediments, subjected to both contact and pressure metamorphism: the reason why the third type shows less pressure effects than the others is due to the flowing of the mostly calcareous rock. The first two were originally finely banded sand-silt rocks, somewhat of the varve type, while the third was an impure limestone. From the material available it is impossible to draw any conclusions as to the mutual relations of these three rocks.

The Schists of Changkat Papan.

At the very outset it will be well to make it clear that none of the specimens described in this section were actually in place, but there is no doubt that they were all very near their original home. All the schist seen by me in place at this locality was too much decomposed for petrographical examination, as so often happens in the Kinta Valley. The descriptions of these loose blocks collected by myself are included here because the field-relations of the limestone, the schist series and the granite are the same as at Gunong Terendum.

The locality called Changkat Papan [1] lies on the eastern side of the southern part of the great limestone hill Gunong Tempurong, 2,005 feet, the highest of all the limestone hills of Kinta. It is about a mile to the N.E. of the small village of Sungei Siput: the road to this village leaves the main road at Kuala Dipang, about 7 miles south of Gopeng. The topography is of exactly the same type as at G. Terendum, namely, an enormous limestone cliff facing east, with a narrow gorge occupied by a strip of schist between it and the granite range, which is here also very steep. The scenery is wonderful: the great limestone cliff, which is nearly vertical for at least 1,000 feet, is perhaps the most striking of all these characteristic features of the Kinta Valley.

(The rock-specimens in this collection bear numbers R.10.1, etc., corresponding to my field notebook.)

Petrographical Descriptions.

R.10.1 and R.10.1*a* are quite similar and may be taken together: there is no hand-specimen. They consist essentially of felspar and either pyroxene or amphibole, or both. Felspar is abundant in

[1] This name does not appear on the 1 inch map of the F.M.S. Topographical Survey, Sheet 2 N/9 (Batu Gajah), but it seems to be well known locally. Of course it has nothing to do with the village of Papan on the west side of the Kinta Valley.

large crystals, with albite twinning in fine lamellae, refractive index higher than Canada balsam and extinctions 15–20°. This seems to be near to andesine. The pyroxene is colourless, with strong birefringence and a wide extinction angle : it may be referred to diopside. The amphibole occurs in prisms usually of a pale brownish green colour, with pleochroism (bluish green, pale brown and nearly colourless) and an extinction angle of about 15°. There is a little pleochroic cassiterite (brownish pink to colourless).

The general character and structure of these two slices suggest that the amphibole is secondary after pyroxene. Some of the patches rich in amphibole have something of the appearance of a crush band, although there is not much parallelism in the arrangement of the amphibole prisms. Some of the felspar crystals show bent twin-lamellae.

The rock may be described as a pyroxenite in process of conversion into an amphibolite.

R.10.2.—This is a dark grey, fine textured rock, somewhat sheared, with much pyrrhotite on fractured surfaces and a slightly silky appearance in places. Its naked eye appearance is that of an amphibolite (epidiorite) and it shows a very strong resemblance to the greenstones of the West Cornwall mining district.

Under the microscope it consists of brown and green hornblende, felspar and a little quartz, with pyrrhotite and a little cassiterite. The hornblende varies much in colour in ordinary light, from bright bluish green to brown, according to the direction of the sections, as its absorption is strong. The pleochroism scheme is blue-green, brownish green, clear brown. The extinction angles run up to 20°. The felspar is often granular and sometimes water clear : its optical characters are not easy to determine, but the maximum extinction angle is about 20°. There is a little clear quartz in angular grains. In one vein-like streak cutting across the slice the hornblende is much more blue than elsewhere.

R.10.3*a* is structurally and mineralogically similar to the above, the chief difference being that the amphibole is paler in colour, mainly brown rather than green, and there is more pyrrhotite.

A large hand specimen and a very good slice cut from it at Cambridge are labelled C.P.3. In the hand specimen parts of the rock are exactly similar to R.10.2, while parts are a little paler. The pale part contains less pyrrhotite. In the slice, which is very clean and fresh for an example of this series, parallel structure is much more marked than in the foregoing, but the minerals are the same : pyroxene, amphibole, and felspar with a little quartz. It is unnecessary to repeat the optical characters of the minerals. Some grains of felspar are large enough to show extinction angles up to 20° on twin-lamellae. As a general description it may be said that the rock consists of alternate bands of pyroxenite and amphibolite.

R.10.4 appears to be a sheared arkose, containing some badly developed biotite in rather ill-defined bands. There seems to be a good deal of plagioclase felspar, which is much crushed. Bluish tourmaline is very rare, and is probably derived, not authigenic. This rock does not need further description.

R.10.5.—The high significance of this rock lies in the fact that it is identical with the tourmaline schist found above the limestone at Tanjong Tualang, 12 miles away on the other side of the Kinta Valley.

The minerals are quartz and tourmaline, with very subordinate white mica: no biotite was identified. There is some pyrrhotite in fairly large grains. The tourmaline is pale orange-brown with strong pleochroism (orange-brown to colourless) in small well-formed prisms, or somewhat granular where most concentrated. The quartz is also granular, with crenulated margins and strain-shadows. The small quantity of white mica in ragged flakes may perhaps represent felspar, which was not found.

This rock is very strongly banded and contorted.

R.10.6.—Another amphibolite with abundant felspar, which is very fresh and shows much fine lamellar twinning. There are a few tiny scraps of biotite, but apparently no pyroxene, and a very little quartz. The amphibole is mostly of an olive-green variety (olive-green—pale brown—colourless) with rather strong birefringence. There seems to be also a paler variety with weaker birefringence. The rock is highly mineralized with finely divided pyrrhotite. It does not show much parallel arrangement in the slice, but may be cut parallel to the foliation. There is no hand-specimen.

R.10.7 to the naked eye is a pale grey rock with large rounded pebbles of quartz and a good many cubes of pyrite. It is obviously much sheared and crushed. Under the microscope it consists mostly of quartz, a kind of sericitic material that probably represents felspar, a very little badly developed biotite in very small flakes, and a great deal of sulphide. This is also probably a crushed arkose. There is evidence of a high degree of shearing and brecciation. There probably was a lot of felspar in this rock originally, but I do not think it is an igneous rock: it looks much more like a highly felspathic sediment.

Some of the sulphides have a steely or silvery colour, rather suggestive of stibnite, but the grains are too small for determination.

R.10.8.—Of this rock there is no hand-specimen, but there are two slices, one a very large one cut by Jacobsen. This shows a distinctly banded rock, composed of amphibole, pyroxene, felspar, and quartz in proportions varying in the different bands. The optical properties of the amphibole and the pyroxene are similar to those before described. It is not at all easy to determine the relative proportions

of felspar and quartz, since the felspar is for the most part water-clear and untwinned, but there is every reason to suppose that it is the same as the felspar in the other specimens, which are in most respects precisely similar. Sulphides, mostly pyrrhotite, are not abundant, but a few unusually large crystals of cassiterite were observed. In some bands the ferromagnesian mineral is almost entirely coloured amphibole, in others almost entirely colourless pyroxene.

Besides these numbered specimens, there is also a large hand-specimen merely labelled " Changkat Papan ", and from this a slice was cut at Cambridge. To the naked eye it is a light greyish-green rock, strongly banded and traversed by a conspicuous yellowish-green vein, nearly at right angles to the bedding. Under the microscope it is seen to consist mainly of quartz and a dirty green mineral, some of which at any rate is epidote, but the greater part is green amphibole of a bluer tint than in the other specimens. The yellow-green vein consists entirely of epidote. Many of the patches richest in quartz have a lenticular form, and there is here again a distinct suggestion of crushed pebbles. It is impossible, without a great expenditure of time, to determine how much felspar there may be in the finer bands. There is an unusually large number of crystals of cassiterite.

This small collection of rocks from Changkat Papan includes three well-marked types :—

(*a*) Sheared arkose.
(*b*) tourmaline-schist.
(*c*) amphibolite.

At first sight the amphibolites look like crushed basic igneous rocks, but probably all of them contain some quartz and as a matter of fact the rock described last forms a transition between them and the arkoses. They are therefore undoubtedly sediments, having an original chemical composition something like that of a basic igneous rock. It is probable, though not certain, that the amphibole is secondary after pyroxene, due to a reaction under pressure between the first-formed pyroxene and a small amount of some iron ore.

The importance of the tourmaline-schist from the stratigraphical point of view has already been emphasized : it proves the identity of these rocks with the strata that overlie the limestone in other parts of the district where the contacts are flat or only slightly inclined.

All the rocks are highly mineralized, with cassiterite and sulphides ; of the latter pyrrhotite is dominant.

Finally, the petrographical examination entirely bears out the idea, based on field evidence, that these rocks have the same relations to the limestone and the granite, as the schists found in place at Gunong Terendum.

The two localities here described, Gunong Terendum and Changkat Papan, which are about 10 miles apart, are on a line of granite-

limestone contact, namely the western margin of the Main Range bathylith, along which similar schists have been found in other places, e.g. the old Kinta Association mine, the neighbourhood of Tambun, Ulu Piah and Pulai. One of these occurrences, mapped long ago by Mr. Scrivenor, not visible at the time of my visit, has since been seen by Dr. Ingham.

The relations of these schists to the limestone must still be left as an open question. It is unsafe without further evidence to assume their identity with the Triassic rocks known as the " Schist Series " in other parts of Kinta, although there can be little doubt in the case of the tourmaline-schist R.10.5. The field evidence appears to indicate that some of the rocks here described may be interbedded with limestone, and the more calcareous types may be due to reaction with the granite magma by diffusion at its contact with the limestone.

I have to thank Mr. Scrivenor and Mr. Willbourn for reading the manuscript of this paper and confirming my recollections of the field-geology, now four years old. They, however, must not be held responsible for any errors that may have crept into the descriptive work.

The Upper Devonian Fishes of Victoria, Australia, and their Bearing on the Stratigraphy of the State.

By Edwin Sherbon Hills, M.Sc. (Melb.). 1851 Research Scholar at the Royal College of Science, London.

(PLATE XI.)

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INTRODUCTION.

THE recent discovery of fossil fishes in the Devonian rocks of Victoria may appear somewhat surprising in view of the fact that the general geology of the state has by now been worked out in

fair detail, both by the Geological Survey and by independent investigators. Much of the detailed work has been confined, however, to the Lower Palaeozoic groups, in which the original gold deposits of the state are found, the economically less important Upper Palaeozoic rocks having been subjected to less minute examination by the Survey, especially of late years, and left in the hands of individual geologists, who often turned to the great igneous rock masses occurring in the central part of the state as constituting a congenial subject for research.

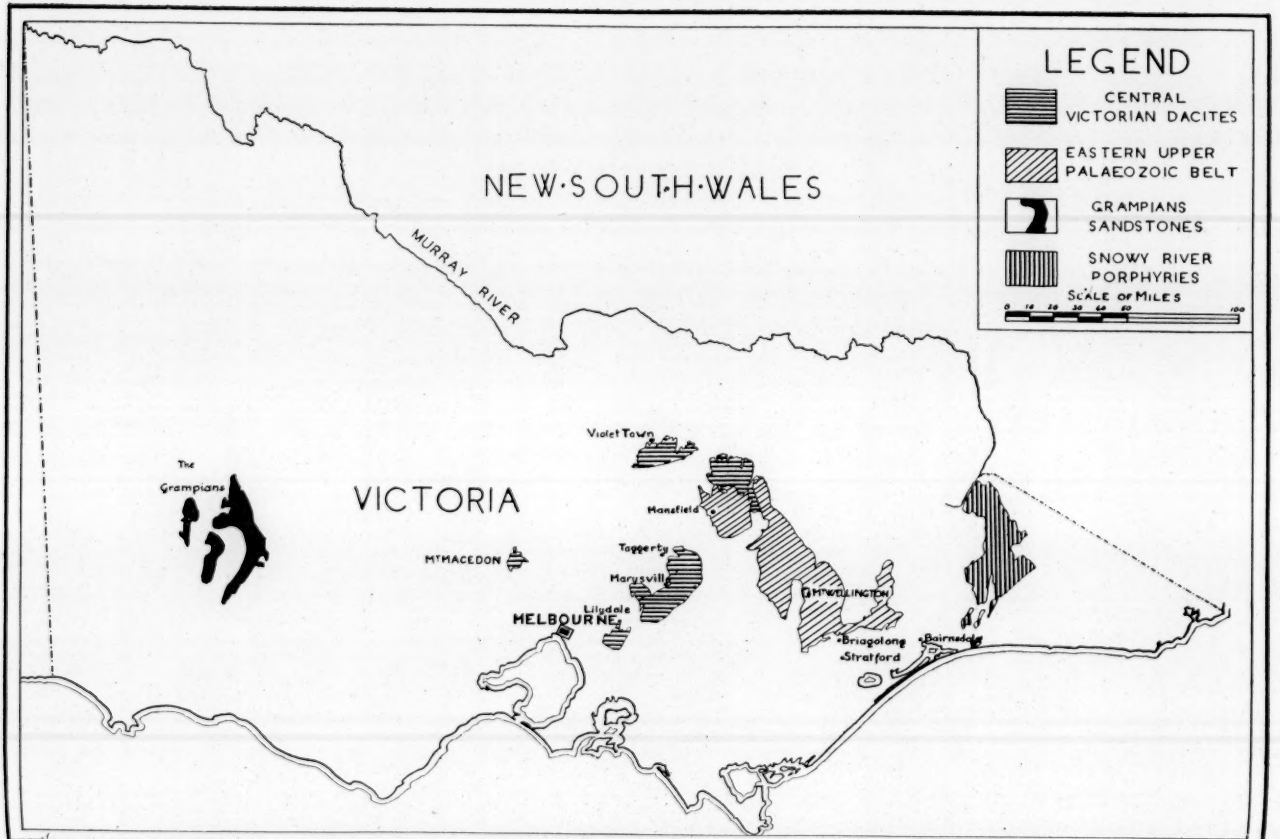
In spite of a great deal of work on these rocks (which are often referred to in general terms as " the dacites and granodiorites "), no coeval fossiliferous sediments were found, and it was only after some years of labour that a consistent account of their geological relations was formulated. Mainly owing to the work of Professor E. W. Skeats and Dr. H. S. Summers in the years around 1910, the conclusion was finally reached that they are of Lower Devonian age, and after that date no evidence was brought forward which might cast serious doubt on the validity of their conclusions, Summers' paper (1914) finally summarizing the available evidence.

There remained to be examined, however, one large area of these Lower Devonian lavas and intrusives, and in 1928 the author, while investigating another formation, was led to examine a small district near that in which these rocks are found. It was in this area near the township of Taggerty that he discovered the first indications of an Upper Devonian fauna yet recorded in Victoria. A short account of the remains was subsequently given (Hills, 1929).

It seemed very likely that by means of these fossils light might be thrown on the question of the age of the dacites, and it remained to work out the field relations of the formations involved. This was done, and the results of the investigation will be presented later, but we may here remark that the evidence points clearly to the fact that the dacites overlie the Upper Devonian formations and are so intimately related to the igneous rocks of that series that all must be considered to be of the same age. The dacites are not Lower Devonian but Upper Devonian, and it becomes necessary to see in what way our conception of the correlation of Victorian Upper Palaeozoic rocks is to be modified by this change of viewpoint.

In the eastern part of the state there is an extensive belt of rocks upwards of thirty miles wide, that stretches for seventy-five miles from the Tertiary plain in the south, near Bairnsdale and Stratford, in a north-westerly direction to the neighbourhood of Mansfield and Tolmie. Here are found thick masses of gently folded red beds—conglomerates, grits, sandstones, and shales—with towards the base of the series many important intercalated flows of felstone and melaphyre.

Our knowledge of the stratigraphy of this belt has been gained as a result of the labours of numerous workers in scattered areas,


LEGEND
CENTRAL VICTORIAN DACITES
EASTERN UPPER PALAEOZOIC BELT
GRAMPIANS SANDSTONES
SNOWY RIVER PORPHYRIES
SCALE OF MILES
0 10 20 30 40 50 100
NEW·SOUTH·WALES
MURRAY RIVER
VICTORIA
The Grampians
Violet Town
Mansfield
MT MACEDON
Taggerty
Marysville
MT WELLINGTON
Lilydale
MELBOURNE
Briagolong
Stratford
Bairnsdale

so that it is hard to arrive at any general conclusions, especially in view of the fact that much of the work was done rapidly in what was at the time almost unexplored country, no detailed mapping being possible. Furthermore, the rather scanty palaeontological evidence, consisting of fish and plant remains from the north and south of the belt respectively with rare records from the intervening country, seems to be contradictory, and it is therefore with interest that I am able to describe below a small collection of ostracoderm fishes made by the officers of the Geological Survey some years ago from the southern part of the belt, at Freestone Creek.

In Part 1 of this paper all the known Victorian Upper Devonian fishes are described, while in Part 2 their bearing on the interpretation of the geology of the state is discussed.

PART 1.

GENERAL ACCOUNT.

1. The Fauna of the Blue Hills, Taggerty.

The discovery of Upper Devonian fishes was made in 1928 near Taggerty in the County of Anglesey, some fifty miles north-east of Melbourne. The fossils were found on the western slopes of the Blue Hills, a range forming one of the foot hills of the Cerbereans which lie to the east, culminating in Mount Torbreck (4,995 feet). The Devonian rocks are of continental origin, the fossiliferous beds consisting of an irregular series of red sandstones and blue shales beneath a great series of predominantly acid lavas which constitutes the main Upper Devonian rock type. (Hills, 1929.)

The collection on which the original description was based consisted mainly of fragmental dipnoan remains associated with plant stems from the blue shales, with two fragments of *Bothriolepis* and a Phyllolepid plate from the underlying red sandstones. The list given was as follows :—

Ostracodermi.	*Bothriolepis gippslandiensis*, sp. nov.
Dipnoi.	*Eoctenodus microsoma*, gen. et. sp. nov.
	Holonema cf. *rugosum* Claypole sp. 1883.

Further collecting has been done at the spot indicated on the map (1929) as well as at outcrops some chains further south along the strike, and has yielded abundant isolated plates of *Bothriolepis* and Phyllolepidae, as well as the teeth, scales, etc., of *Dipterus*, to which on further consideration the author has referred the remains first described as *Eoctenodus*, gen. nov.

Only shallow excavations were attempted, and as a result most of the boney material is so weathered that is is extremely friable. This, however, is not detrimental since the matrix of the Ostracoderm remains is hard and finegrained, so that by brushing and washing the specimens exquisite moulds can be obtained that preserve the details of surface ornamentation. Most of the plates

are crushed and faulted, though some have escaped distortion. All the available material was transported from Australia and studied under the more favourable conditions existing in London, as a result of which the following forms are described below :—

HETEROSTRACI. Phyllolepidae, genera indet.
ANTIARCHI. *Bothriolepis gippslandiensis* Hills, 1929.
CTENODIPTERINI. *Dipterus microsoma* (Hills, 1929).

It is evident that we have to deal with a typical Upper Devonian fauna, for *Bothriolepis* and the Phyllolepidae are characteristic of that epoch wherever they occur, in Europe, North America, Spitsbergen, Ellesmere Land, and even Antarctica, while *Dipterus*, although more especially Middle Devonian, ranges upwards in Britain and Greenland. Moreover, the characters of the Victorian species are such as would indicate that it is geologically younger than the Middle Devonian forms of the same genus. The assemblage as a whole demonstrates the remarkable stability of that group of fishes which characteristically occurs in Upper Devonian deposits of Old Red Sandstone facies over widely separated areas of the earth's surface, *Holoptychius*, however, being a notable absentee.

2. THE FAUNA OF FREESTONE CREEK.

It was with interest that the author learnt, a short time before leaving Australia, of the existence of an undescribed collection of fossil fishes from the southern part of the eastern Upper Palaeozoic Belt near Briagolong, and he is much indebted to the Director of the Geological Survey of Victoria, Mr. W. Baragwanath, both for permission to transfer the collection for England to study, and for supplying an extract from his notes on the geology of the fossil locality.

The exact situation is stated to be Pheasant Gully, a tributary of Freestone Creek, about five and a half miles north of Briagolong township, in the County of Tanjil. It is thus about a hundred miles to the east of the Upper Devonian beds at Taggerty. Although no precise details of the geology are available, it seems certain that in the area under consideration we cannot be far from the base of the Upper Palaeozoic rocks, as Howitt (1876, p. 222) noted the basal conglomerates and felsites along Maximilian Creek (a tributary of Freestone Creek) resting unconformably on the underlying older beds. Murray (1878), who traced the Iguana Creek beds (basal Upper Palaeozoic) round to Freestone Creek, " found in the latter locality fossil flora, among specimens of which Professor McCoy recognized *Cordaites australis* McCoy, a characteristic fossil of the Iguana Creek strata, and indicative of Upper Devonian age (see also p. 226).

Mr. Baragwanath supplies the following details :—" The Upper Devonian beds at this point are one mile from the outcrop of the underlying strata, and allowing for the dip of the Upper Devonian

would make the fossil locality some 500–1,000 feet above the basal beds . . . and I think the fish horizon would be just above the plant beds of Iguana Creek."

The fossils occur in dark grey micaceous sandstones, throughout which the plates are scattered irregularly but abundantly, being sometimes in groups as if collected by currents. Here also, as at Taggerty, it is believed that the conditions of sedimentation were "essentially terrestrial, accompanied by the development of several lacustrine basins" (Teale, 1920). The fossils are thoroughly decomposed, and again use has to be made of the moulds, which in this case are not of quite the same degree of fineness as the specimens from Taggerty, since the matrix is coarser grained and softer. However, details of surface ornamentation are well preserved, and no trouble was experienced in removing all traces of the dark brownish-black bone.

The fauna is a small one, but is remarkable in that we again meet with *Bothriolepis gippslandiensis* Hills, by far the greater part of the specimens consisting of the isolated plates of this species. As is explained more fully later, the author experienced some difficulty in finding out the exact nature of the relationship between the forms from this locality and those from Taggerty, but he finally concluded that we have to deal with what can only, in the present state of our knowledge, be regarded as the remains of many young individuals of the species *B. gippslandiensis*. A few small spines of a new type are also represented in the collection, together with some indeterminate scales and cranial bones. The faunal list is as follows:—

ANTIARCHI. *Bothriolepis gippslandiensis* Hills, 1929.
ICHTHYODORULITES. *Striacanthus sicaeformis* gen. et spec. nov.

The presence of *Bothriolepis* is sufficient to indicate an Upper Devonian age, especially as the species is that found with the larger and more distinctive fauna at Taggerty, while the presence of that species in the deposits of these widely separated areas leads us to seek other connections between them, where formerly none were suspected.

Having thus briefly considered the geology of the districts concerned, we now turn to the systematic treatment of the fossils themselves, in which the remains from both localities will be considered together, the arrangement being, as far as possible, taxonomic.

3. PALAEONTOGRAPHY.

Note.—Throughout this section numbers in brackets [ ] refer to registered specimens in the Museum of the Department of Geology, University of Melbourne, numbers in parentheses ( ) to those in

the author's collection, and other numbers to specimens registered in the Geological Survey Museum, Melbourne.

Class, OSTRACODERMI.
Subclass, *Pteraspidomorphi.*
Order, Heterostraci.
Phyllolepid plates.

Locality.—Blue Hills, Taggerty, Victoria. Upper Devonian.

Type 1.—Fragments of polygonal plates bearing a coarse ornament of rounded asymmetrical ridges sub-equal in width to the intervening furrows (Fig. 2, Nos. 1, 2).

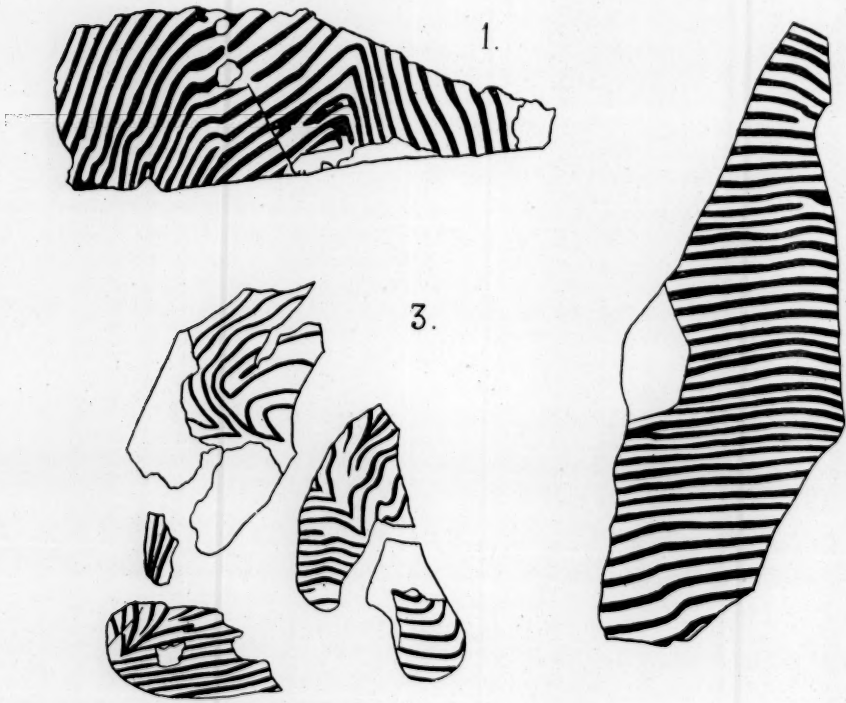


Fig. 2.—Phyllolepid plates. Blue Hills, Taggerty. No. 1 [791] × $\frac{5}{8}$ and No. 2 (T.3*a* P) represent the type with coarse ornament; × $\frac{3}{4}$. No. 3 (T.1*a* P) the type with fine ornament. × 2.

Since the plates formed part of a mosaic it cannot be determined whether the ornament is radially or concentrically arranged. None of the specimens can be matched with any of the dorsal plates of *Phyllolepis*, and the equality of ridges and furrows is not so well marked in that genus as in the plates from Victoria. When first recorded from this locality (Hills, 1929), similar plates were referred to *Holonema*, but the author now believes that a generic determina-

tion is not warranted, in view of the very fragmentary nature of the remains and the fact that the characters of the Phyllolepidae are not at all well known.

The microscopic structure of the plates is shown diagrammatically in Fig. 3. There is an outer lamellar layer L, which forms a continuous layer in which the lamellae are parallel to the surface of the plate though the waves shift somewhat laterally in depth, and finally merge into the middle vascular layer H. This has numerous branching canals round which there is often a concentric arrangement of bony material marked by light and dark bands. Bone cells seem, however, to be absent (though it may be that the mode of preservation does not allow them to be distinguished), and these canals cannot be termed " Haversian " (see also Heintz, 1929). Indeed, no bone cells have been observed in any part of the plate, and the absence of these, as well as of dentinal tubules in the outer lamellar layer, make the homologies of the various parts of the plate uncertain. The basal layers show no traces of lamellar structure; they contain lacunae in places, although the under surface remains smooth.

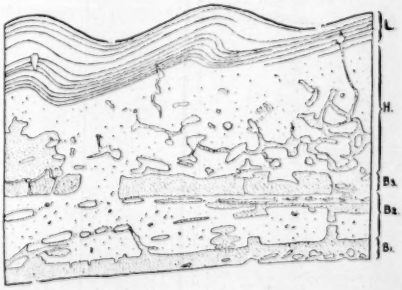


Fig. 3.—Section of a Phyllolepid plate. Type 1, with coarse ornament. × 25. B1, B2, B3, basal layers. H, middle vascular layer. L, outer lamellar layer.

Type 2.—Fragments of polygonal plates, thinner than the above, and bearing a delicately ridged ornament in which the ridges are irregularly meandrine and widespaced. One of the specimens (Fig. 2, No. 3) seems to have belonged to a median series, and the ornament is roughly concentric, but it cannot be compared with any of the plates of *Phyllolepis*, and is quite distinct from the *Holonema* type.

Class, PISCES.

Subclass, *Elasmobranchii* (?)

Ichthyodorulites.

Genus, *Striacanthus* nov.

Striacanthus sicaeformis gen. et sp. nov.

Locality.—Pheasant Gully, Freestone Creek, 5½ miles north of Briagolong, Victoria. Upper Devonian.

The fish spines which accompany the preponderating *Bothriolepis* plates at the above locality are unique in that the base of insertion is longitudinally striated, which character seems to be of sufficient importance to warrant the erection of a new genus to embrace the remains. The exserted portion is also longitudinally striated, the relation between the two parts being best seen in the holotype, specimen F.Ck. 16 (Fig. 4, No. 1). The surface is quite smooth (apart from the striae) no denticles or hooks being present, and the whole is gently curved, suggesting the specific name (Lat. *sica*, a dagger). Although the substance of the spines is wholly decomposed, it can be seen (Fig. 4, No. 3) that there was a central longitudinal pulp cavity with smaller tubes arranged concentrically around it parallel to its length.

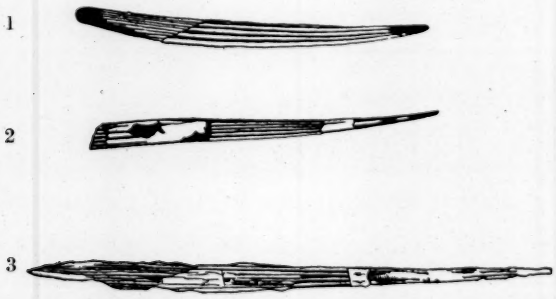


FIG. 4.—*Striacanthus sicaeformis* gen. et spec. nov. 1. Mould of the exterior of F. Ck. 16, showing the finely striated base of insertion; × 2. 2. Mould of the exterior of 149 : 20 with some pieces of decomposed spine still adhering; × 2. 3. Mould of the exterior of 25470 : 3, showing the finely striated base of insertion, and indications of the cylindrical pulp cavity (now filled with matrix) at the narrow distal end; × 2.

Subclass, *ELASMOBRANCHII* (?)
Order, ANTIARCHI.
Genus, *Bothriolepis* Eichwald, 1840.
Bothriolepis gippslandiensis Hills, 1929.

Locality.—Pheasant Gully, Freestone Creek, 5½ miles north of Briagolong, Victoria; and Blue Hills, Taggerty, Vic. Upper Devonian.

Introduction.—The original description of this species was based on a dorsal external marginal of the right appendage and an incomplete median occipital. The new collection contains many isolated plates that have all been referred to the above species, and it is interesting to discover that the median dorsal body plates

bore as " elevated lamellar crest " such as is known on only three other specimens of *Bothriolepis*. Traquair used this crest as the distinguishing character of the species B. *cristata* Traq. (which is known only from the Upper Old Red Sandstone of Scotland), the other features of the species being very incompletely known, especially the head, which is not present on the type specimens, and the lateral appendages. Thus the holotype of *B. gippslandiensis* Hills cannot be compared with that of *B. cristata* Traq., but it might appear at first sight that the presence of the crest would be sufficient to show the identity of the two. This, however, does not prove to be the case, and the specific identity of the Victorian forms must be maintained.

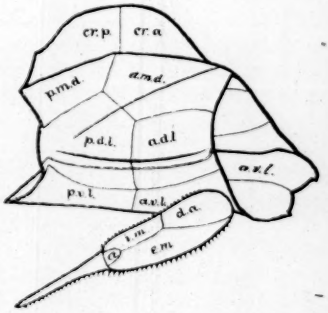


FIG. 5.—Reconstruction of the body armour of *Bothriolepis gippslandiensis* Hills. A.M.D., anterior median dorsal. P.M.D., posterior median dorsal. Cr.A., Cr.P., anterior and posterior parts of the crest. A.D.L., anterior dorso-lateral. P.D.L., posterior dorso lateral. A.V.L., anterior ventro-lateral. P.V.L., posterior ventro-lateral. E.M., dorsal external marginal. I.M., dorsal internal marginal. D.A., dorsal articular. A, anconeal. The relative length of the arm is approximate only. Size is about half that of the oldest individuals found at Taggerty, but the crest as restored is a little too high. Cf. Fig. 7 for exact dimensions.

Traquair in his original description of the Scottish species (1896) and subsequently in his monograph for the Palaeontographical Society (1913) wrote that the " singular median dorsal crest distinguishes this species from all other members of the genus *Bothriolepis* ".

As specific characters he mentions only the crest and the type of ornament, but in the text he says that " the carapace appears slightly narrower in proportion to its length than is ordinarily the case with *Bothriolepis* ". There seem to be no denticles on the lateral appendages, and as far as can be seen from his figures the carapace is of the typical " box-like " shape with a well-marked angulation in the lateral plates. In all these points the species is quite distinct from *B. gippslandiensis* Hills in which the carapace tends to be

short in proportion to its length, denticulation of the "arms" well-marked, and the carapace rather of the highly arched *Pterichthys* type than "box-like" with angular sides. This is reflected in the lateral plates, whose shape, especially that of the posterior dorso-lateral, differs markedly from that of similar plates in *B. cristata* Traquair.

It would seem, therefore, that among crested Bothriolepids variations occur such as serve to differentiate the species of non-crested forms, and it may be that there are two distinct stocks in the *Bothriolepis* lineage, one crested and the other not. Since the relations of the various branches are not known, they are both referred to *Bothriolepis* in this paper, as no useful purpose would be served by subdivision of the genus on what might appear to be inadequate data. It should be noted, however, that although conforming to the definition of *Bothriolepis* based on the course of the lateral-line system and the overlap of the plates, *B. gippslandiensis* seems to depart from the generic line in the shape of the carapace and the fact that the post-median plate is laterally elongated as in *Asterolepis* and *Pterichthys*.

The remains from Freestone Creek at first sight look very different to those from Taggerty, as there occur at the former locality scores of isolated plates whose average size is perhaps only one third the linear dimensions of the large and most striking plates from the latter. These large plates have a tuberculate ornament, while all the plates from Freestone Creek have a beautifully delicate reticulate sculpture, so that it seemed that there was a different species at each place, as indeed might have been expected, since there had been no suggestion that the deposits of the two areas were in any way connected.

It was of great interest therefore to discover on further examination that the remains from Freestone Creek belong to the crested type of *Bothriolepis*, and the results of detailed study show that, when the complete range of variation at each locality is considered, there is indeed no means of distinguishing the two series of plates. Extensive and detailed measurement serves only to bring out the points in which both the large and small plates differ from other species—as for example in the unique anterior median dorsal, which is wider than it is long, and in the tendency for almost all the plates to be shortened antero-posteriorly. Also the examination of the complete suite at Taggerty revealed the presence of small plates indistinguishable from similar ones at Freestone Creek, as well as others intermediate in size between the two extremes. The ornament of these is of intermediate type also, and may readily be derived from that of the smaller plates by deposition of more material over the surface, leading to a coarsening of the reticulation and an accentuation of the nodes or plexi. As further deposition goes on many of the smaller pits are entirely buried, and finally a stage is reached in which the ornament consists of rather widely

spaced tubercles. All these stages may be seen in the plates from Taggerty, and in each case the size and ornament are compatible.

Others have noted changes in the armour during ontogeny, Traquair especially remarking on the increased coarseness of the sculpture with advancing age (1913). Kiaer (1915) also notes that the young of *B. canadensis* (Whiteaves), has a sculpture which is " apparently very close to that which is characteristic of the remains described above " [*B. hydrophila* (Agassiz)]. This is another instance of the development of a tuberculate (*B. canadensis* mature) from a reticulate (*B. canadensis* young) type of ornament. There are often indications of the youthful type of ornament on certain parts of the plate where deposition of further material seems to have been restricted, especially in the region of the growth centres. This has been observed by the writer in the case of *B. canadensis* (Whiteaves), and is also found in some of the large plates from Taggerty (Plate XI, Fig. 1).

Another point which shows that the small plates really belong to young individuals is that on the anterior median dorsal of specimens up to the size of that figured in Plate XI, Fig. 4, there is a ridge of ornament running laterally from the angulation of the slime canal to the anterior corners of the plate. This is absent from the larger plates. Such a line (and a similar one on the posterior median dorsal parallel to the hinder edge) is also present in the young of *B. canadensis* (Whiteaves), but is absent from older individuals, while a similar feature has been observed by Kiaer (1926) in plates from Novaya Zemlya. He says " the other fragments do not show this line " but gives no dimensions from which the ages might be inferred.

From the above considerations the writer concluded that the closeness of the relationship of the remains from the two localities is such that we can only express it at present by referring all to the one species, such small differences as are found being due to individual variation, and the small plates belonging to young examples. Further detailed collecting from Freestone Creek would obviously be of value.

Description.

Median occipital.

In the original description of the holotype [776], the length of the median occipital was given as 0·9 cm. This refers only to the ornamented part, behind which is an unornamented strip about 0·3 cm. wide, that was overlapped by the anterior median dorsal but was free to move under it during slight up and down movements of the head. This is shown by the fact that whereas the rigidity of the overlappings of the body plates is provided for by countersinking the edges of adjacent plates, in this case the overlapped part is continuous with the exposed surface of the bone.

The notch for the insertion of the post-median is shorter antero-posteriorly than laterally, and this is a distinctive character, as the opposite is generally the case in *Bothriolepis*. Although laterally elongated the post-median does not meet the laterals at the surface as it does in *Asterolepis* and *Pterichthys*, but it is interesting to note that owing to the peculiar bevelling of the median occipital (Fig. 6, No. 1), it does so in the thickness of the bone.

Details of the shape of the plate can be made out from the figure, and it can be seen that there are many points of difference from *B. canadensis* (Whiteaves), the only other species at all well known.

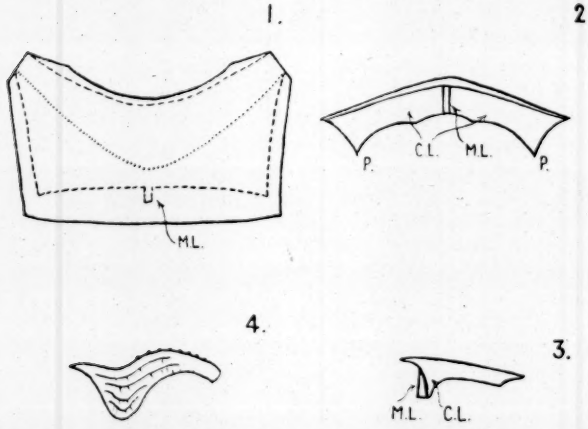


FIG. 6.—No. 1. Median occipital of *B. gippslandiensis* Hills; dorsal view. The dotted line represents the sensory groove, the broken line the outline of the under surface of the plate, and the full line that of the upper surface. M.L. = median lamina. × 2. No. 2. Median occipital of *B. gippslandiensis* Hills; back view. M.L. = median lamina; P = downwardly projecting points; C.L. = cross lamina. × 2. No. 3. Median occipital of *B. gippslandiensis* Hills; median section. M.L. = median lamina; C.L. = cross lamina. × 2. No. 4. Median occipital of *B. canadensis* (Whiteaves); median section. After Patten, 1912. × 2.

Essentially the same structures are present in each, however, though they differ in proportion. Attention may be drawn to the bony points P, projecting down from the vertical cross lamina C.L., and the small median lamina M.L. at right angles to this. These structures are also present on the median occipital of *Pterichthys* (the author is indebted to Professor D. M. S. Watson for the loan of a well preserved head of that genus), though modified because of the smaller size, so that it is evident that they have some relation to the essentials of the Asterolepid armour.

Premedian.

As is usual with *Bothriolepis* this is not notched in front. The deeply incised slime canal is plainly marked, and on the inner

surface is a horizontal lamina such as is shown by Patten (1912) on *B. canadensis* (Whiteaves) but in the Victorian species it is situated further anteriorly. The very delicately reticulate ornament is arranged parallel to the posterior border in the middle of the posterior part of the plate.

Laterals.

In the original description of [776] it was stated that the slime canals " appear to bend round at the sides of the latter [the orbit], instead of further anteriorly as in *B. canadensis* and *B. hydrophila*. Fracturing and displacement of the plates during preservation has, however, rendered the paths of these grooves outside the median occipital uncertain." Subsequent removal of more of the matrix shows that the right lateral has been displaced and its anterior end swung round in front of the orbit. The course of the slime canal is the same as in other species. Round the border of the orbit the ornament is concentrically arranged, as on the premedian. It should be noticed that the orbits are roofed and not floored by the laterals as is stated to be the case in *B. canadensis* (Whiteaves).

Oral apparatus.

Lying in the position of the orbits is a small gently tapering bone which may possibly represent part of the oral apparatus pushed up into contact with the dorsal bones of the head.

Anterior median dorsal.

Remains of this characteristic plate are numerous, especially at Taggerty, where eight examples have been found, although only one posterior median dorsal is known from the same locality. Perhaps the most remarkable feature is the crest, which rises to a height of one centimetre from a plate 3·6 cm. in legnth, and 4 cm. broad. At its base it is 0·2 cm. thick, but it tapers upwards to a thin edge. On the above plate, which is the largest obtained, there is practically no ornament on the crest, and in the specimen shown in Plate XI, Fig. 4, we have an intermediate stage in which it is reduced to rather widely spaced pits arranged along vertical lines. This arrangement is due to a modification of the youthful ornament of rather irregular vertical ribbing, seen on one small specimen from Taggerty and one from Freestone Creek (Fig. 7, No. 3). The sunken areas on the edges of the plate due to overlap are always easily seen, and the overlap arrangement is that usual in *Bothriolepis*. The V-shaped slime canal is situated as in other species of the genus, and it bends round in the middle line just where the crest begins to rise.

Young individuals have a ridge of ornament (Plate XI, Fig. 4) running from the bend in the slime canal out to the antero-lateral corners, and a similar feature of plates from Novaya Zemlya is according to Kiaer (1926) " only a radial interruption of the surface sculpturing ". With this the present author agrees.

All the plates measured, ranging in length from 1 cm. to 3·6 cm., are remarkable in that they are slightly wider than they are long, which is the case with no other species of *Bothriolepis*, or indeed any other Asterolepid. Details of the structure of the inside of the plate may be compared with Patten's account (1913) of *B. canadensis* (Whiteaves). An area A (Fig. 7, No. 3) round the apex is

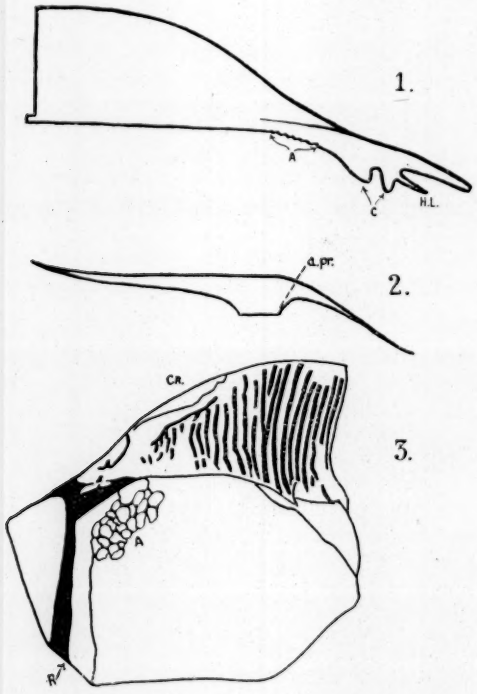


FIG. 7.—No. 1. Median section of a large anterior median dorsal of *B. gippslandiensis* Hills. A = roughened area for the attachment of ligaments; C = bony cylinder, projecting downwards; H.L. = horizontal lamina. × 3. No. 2. Median section of the anterior median dorsal of *B. canadensis* (Whiteaves). After Patten, 1912. a.pr. = anterior bony entapophysis. No. 3. Anterior median dorsal of *B. gippslandiensis* Hills from Freestone Creek. F. Ck. 16. The drawing shows the internal surface of the left lateral lamella, and the outer surface of the right side of the crest, both as impressions. Cr. = Crest; R = anterior ridge; A = roughened area, for attachment of ligaments. × 4.

roughened, probably for the attachment of strands of ligamentous connective tissue. A smoothly rounded ridge R (Fig. 7, No. 3) is present near the anterior border and runs across the plate, and in the middle line a small cylinder of bone projects downwards

(C). Anterior to this is a thin horizontal lamella H.L., which may have served to support the back end of the median occipital. That these structures differ from those of *B. canadensis* (Whiteaves) is seen from the sections given.

Posterior median dorsal.

Only one poorly preserved specimen of this plate is known from Taggerty, but this is sufficient to show the shape of the crest and the thickened posterior border of the bone. The crest seems to have been devoid of ornament. The specimen occurs on the same slab as the largest anterior median dorsal, whose crest is also devoid of ornament. Two small plates are known from Freestone Creek, but in each the crest is buried in the matrix. The length and breadth (twice the width of one lateral lamina) are practically equal, as is usually the case in *Bothriolepis*.

Posterior dorso-laterals.

In this plate the angle between the lateral and dorsal laminae is small, and this results in the production of a carapace which is highly arched as in *Pterichthys* and not box-like as in most species of *Bothriolepis*. The angle between the edges that make contact with the two median dorsal plates is small also, so that the posterior median dorsal slopes rather steeply backwards. The lateral line and dorsal slime canal are both well marked, the latter terminating before reaching the former. There is a rounded ridge on the inside of the posterior border.

Anterior Dorso-lateral.

Owing to the *Pterichthys*-like shape of the body carapace, the dorsal and lateral lamellae make only a small angle with one another. At the anterior end a lamina of bone projects forwards and downwards parallel to the front edge, and presumably performed some function in connection with the articulation of the head.

Anterior ventro-laterals.

One especially fine specimen (Plate XI, Fig. 5) from Taggerty has the proximal part of the arm still in position though fractured, and the median ventral and part of the other anterior ventro-lateral occur on the same slab. There is an internal vertical lamina running laterally at about the position of the " helmet process ", and in the case of young individuals there is a slight ridge in a corresponding position on the outside.

The posterior ventro-laterals and median ventral have no features of special importance, except that the posterior termination of the former is square-cut and not rounded.

Brachial plates.

Strong denticulation of the internal and external marginals is always well shown, and the ornament even in mature individuals

consists of subparallel ridges and cross ridges, producing a fine rectangular reticulation. The paratype is a dorsal external marginal of the right appendage. In the reconstruction the relative length of the arm compared with the rest of the carapace is approximate only.

Ornament.

As will have been gathered from the above account, the ornament is very variable, and the writer considers that unless due weight be given, in using this character as a specific determinant, to the age of the individual in question, the conclusions reached will have little value. In most of the plates of *B. gippslandiensis* Hills there is a very distinct tendency towards concentricity, although in the older tuberculate stages this tends to be obliterated.

Subclass, *Dipnoi.*
Order, Ctenodipeterini.
Genus, *Dipterus* Sedgwick and Murchison, 1835.
Dipterus microsoma (Hills, 1929).
Syn., *Eoctenodus microsoma* Hills, 1929.

Locality.—Blue Hills, Taggerty, Victoria. Upper Devonian.

Fig. 8.—Sketch section showing the general sequence of Upper Palaeozoic rocks in the southern part of the Eastern Upper Palaeozoic belt. After Murray, 1878. a = Silurian; b = Upper Palaeozoic conglomerate; c = Metaphyres; d = conglomerate; e = Metaphyre; f = coarse sandstone; g = Porphyry; h = hard fissile gritty shales; i to j = alternating conglomerates, thick and thin bedded.

When the writer originally described the remains of Dipnoans from Taggerty no material was available for comparison, and since he has had the opportunity of seeing Dipnoan remains in the Natural History Museum and in the collection of Professor D. M. S. Watson he has revised his former views, and rejects the genus *Eoctenodus*. The isolated bones from Taggerty are all of Dipterine type, and cannot be separated from *Dipterus*. *Phaneropleuron* has too few teeth on the dental plate (6–7 instead of 9–11) and so has *Scaumenacia*, which differs also in having no forward process from the fused parietals and interparietals, and unexpanded pterygoid, and very fine radiating lines on the scales which are absent from the Taggerty examples. (See Hussakof, 1911.) The dental plate of *Pentlandia* is unknown, and thus the remains have been referred to *Dipterus*. Indeed, there are very few points of difference from *D. platycephalus* Pander except that the parasphenoid in that

species has a short shaft and in the Victorian a long tapering one, and the number of teeth is usually given as twelve ; but this may be less. According to Professor Watson's views, the length of the parasphenoid shaft is of some importance as it may represent the result of the fusion of the anterior cervical vertebrae on to the back of the skull. Thus the implication is that the forms with a long shaft are geologically younger than those with a short shaft, so that the Victorian remains would be younger than *D. platycephalus* Pander, which is Middle Devonian.

The newly collected material includes two dental plates and a parasphenoid agreeing in type with the remains already known, and a thin flat bone of rather rectangular outline, perhaps an operculum.

Incertae sedis.

Fish scales and cranial bones.

Locality.—Freestone Creek. Upper Devonian.

A very few small isolated cranial bones and scales which do not admit of determination occur in the *Bothriolepis* bed at Pheasant Gully, Freestone Creek, and suggest the possibility of further discoveries being made in these beds.

Taxonomy.

In placing the Phyllolepidae with the Heterostraci the writer has followed Smith Woodward (1920), while the work of Stensiö (1927) has shown that the class Ostracodermi (sensu stricto) is very specialized, and probably does not contain the Antiarchi, which he considers are " true fishes related to the Elasmobranchs ".

PART 2.

INTERPRETATION OF RESULTS.

The problems presented to the student of Victorian stratigraphy by the Devonian and Carboniferous systems have previously been rendered very difficult of solution because of the lack of reliable palaeontological evidence, and much of the importance of the fishes described above lies in the precise definition they give to the age of the beds in which they occur. We may perhaps best indicate their significance by considering some of the special problems on which they throw some light.

1. The Age of the Central Victorian Dacites.

These rocks, which constitute some of the main mountain masses in the central part of the state (see map), are acid lavas whose thickness, though hard to estimate with any degree of accuracy, must be very great, and whose former extent may in all probability have been much greater than at present. It will be of little value to enter exhaustively into the history of the development of ideas as to their exact age, but we may note that Selwyn and the early

workers regarded them as Palaeozoic " of later date than the lower Silurian period ; there is no evidence of their being younger than those formations classed as upper Palaeozoic or lower Mesozoic " (Selwyn, 1866). Professor J. W. Gregory, on the other hand, maintained (1902) that they are much younger, perhaps even of Lower Cainozoic age. As further studies were made of the field and petrological relations of these and similar rocks, however, data were found to support rather Selwyn's ideas than Gregory's, and in 1908 Summers was able to demonstrate that certain quartz porphyries near Nillahcootie, north of Mansfield, are intrusive into Silurian rocks and overlain unconformably by Lower Carboniferous conglomerates and sandstones. Thus the conclusion was reached that these porphyries are of Devonian age, and moreover, as he points out in a further important paper (1914) probably Lower Devonian, since " enormous earth movements marked the opening of the Devonian in Victoria, and . . . the inference is that the intrusion of these igneous rocks accompanied these Lower Devonian earth movements . . ." (p. 260).

Now the field evidence shows that these quartz porphyries are the same age as rocks further west near Violet Town, which on the basis of chemical and petrological evidence he regards as comparable with the disconnected areas of dacite in the central portion of the state, so that " the dacites and grano-diorites of Macedon, Dandenong and Healesville, in the absence of other evidence, may be classed as Lower Devonian ". Some further support for this idea was adduced from the fact that in eastern Victoria a large series of acid lavas, the Snowy River Porphyries, has been shown by Howitt (1890) to be of Lower Devonian age (perhaps) so that igneous activity during that epoch might be expected in other parts of the state as well.

Although nothing bearing directly on the problem in hand was subsequently discovered, both in the Grampians and in the east important intrusions of post-Lower Carboniferous (Skeats, 1923) and post-Middle Devonian (Skeats, 1929) age respectively were found, so that " . . . the long maintained view that notable compressive earth movements with accompanying plutonic intrusions ceased in the Lower Devonian period cannot now be entirely accepted ". (Skeats, 1929.)

It was clearly important, therefore, that the relations of the Upper Devonian rocks of Taggerty to the neighbouring dacites (well exhibited in the Marysville district) should be investigated, and this study the writer undertook in 1929. While the detailed results of that investigation will be given in another place, the evidence presented was sufficient to leave no doubt that the dacites form merely the latest phase of the igneous activity whose earliest manifestations are represented by the Upper Devonian lavas of Taggerty. The dacites overlie the southern extension of these lavas, and occupy the centre of what appears to be a broad synclinal

at whose edge the rhyolites shown by the fish remains of Taggerty to be Upper Devonian, form a steep and high escarpment, breached by only a few large streams.

Similar conclusions as to the stratigraphic relations of certain rhyolites to the dacites near Narbethong, about nine miles west of Marysville, were reached by Junner (1915), and the author has traced these rhyolites in the field from the area mapped by Junner, as a continuous outcrop to Marysville, and thence to Taggerty. Both at Narbethong and Marysville it is impossible to map a boundary between the rhyolite and the dacite, the one type gradually merging by concomitant mineral variations into the other. This, and more detailed chemical and petrological evidence, indicate that there can be no great time interval between the two series of lavas, and that we have to deal with an igneous complex of Upper Devonian age. Since it has already been conclusively shown by many workers that the dacites in the areas above mentioned are very intimately related to those of the outlying areas of Macedon, Lilydale, and Tolmie (see esp. Summers, 1914), it is usual to consider them as all of the one age, which on the evidence above outlined, must be considered as Upper rather than Lower Devonian, as was previously believed.

2. The Granodiorites.

So far but passing reference has been made to the granodiorites and associated intrusive types that in every case accompany the dacites, being genetically related to them. In every case they are described by the latest workers as intrusive into the dacites (Summers, 1923, summarizes the evidence), and this is found to hold at Marysville in the area studied by the author, but it has also been generally believed that both intrusion and extrusion took place so close to each other in time that they are to be considered as belonging to the same epoch.

It is known, however, that some of our granodiorites are post-Lower Carboniferous, being intruded into the Grampians Sandstones (Skeats, 1923), and there are many occurrences in the east of the state whose geologic relations are not well known. For these reasons it will be best to defer further consideration of the intrusive rocks of Victoria until the completion of more field work enables precise evidence to be presented.

3. The Eastern Upper Palaeozoic Belt.

In this district the rocks consist mainly of red beds with intercalated basic and acid lavas, and the palaeontological evidence indicates that both Upper Devonian and Lower Carboniferous deposits are present, although the relations of these two series has been a matter for debate in the past. Since we now know that some connection exists with the rocks of Upper Devonian age in central

Victoria, it may be of value to consider the stratigraphy of the belt in some detail with a view to correlating the results of the various workers.

The first fossils to be found came from the red sandstones of the Avon River, north-west of Briagolong, Professor McCoy in 1874 describing and figuring a new species of *Lepidodendron* from that locality—*L. australe* McCoy—which he considered fixed the age of the beds as Lower Carboniferous. It was not long, however, before other plant remains turned up, this time from Iguana Creek north-east of Briagolong, and these McCoy described in 1876, the flora consisting of *Archaeopteris howitti* McCoy, *Sphenopteris iguanaensis* McCoy, and *Cordaites australis* McCoy, which he says in an earlier publication (1875) are "characteristic of the Upper Devonian".

Influenced by these results, Howitt (1876) tried to separate the two series in the field, with but little success, and later Murray (1878) found "the evidence obtained leaves no doubt as to the rocks of Freestone and Iguana Creeks and those of the Avon belonging to the same series". Indeed, *Lepidodendron australe* McCoy is by no means characteristic of the Lower Carboniferous, since in New South Wales it ranges downwards to the Middle Devonian, and is most characteristically Upper Devonian, although it may range into the Lower Carboniferous (Benson, 1922), so that its stratigraphic value is very small.

In view of the poor state of preservation of all the remains, the presence of two of the species found at Iguana Creek in what appear to be undoubted Upper Devonian rocks in New South Wales affords valuable support to McCoy's verdict on the age of the Iguana Creek beds, for on the Genoa River Dun (1897) records *Archaeopteris howitti* McCoy, *Cordaites australis* McCoy, and *Sphenopteris carnei* Dun, together with *Pecopteris*(?) *obscura* Dun from beds associated with marine fossils.

At the northern end of the Upper Palaeozoic belt near Mansfield, however, fossil fishes which are certainly not Devonian occur, and Smith Woodward who examined them (1906) referred them to the Lower Carboniferous. Slightly higher in the series at the same locality occurs *Lepidodendron mansfieldense* McCoy, a species "quite different from the *Lepidodendron australe* (McCoy) . . . from the Avon Sandstones" (McCoy, 1889). What the relations of the Mansfield, Avon River, Iguana Creek, and intervening districts are it has been difficult to say, the latest worker in the belt (Skeats, 1929) being in favour of the view expressed by the Geological Survey in their map of 1909, i.e. the separation of the Mansfield area from the remainder. When we consider certain aspects of the problem, however, it is possible to arrive at different conclusions, especially when we try to understand the exact horizon at which the fossils occur in each locality, and seek also for lithological analogies between the rocks of the various districts.

(*a*) *The Structure of the Upper Palaeozoic Belt.*

In the southern part of the belt very little work has been done since the time of Howitt, Murray, and Ferguson, and piecing together the evidence they present, it is clear firstly, that, as is emphasized particularly by Murray, 1878, the extensive felsite and melaphyre sheets that figure so prominently in the descriptions of Howitt's explorations are entirely confined to the base of the series. They outcrop always as an escarpment edge to the Upper Paloaezoic rocks where these junction unconformably with the underlying formations, and above them, as shown in Murray's section (Fig. 8) comes a great thickness of red beds without intercalated lavas.

Indeed, Howitt's descriptions (1875, 1876, 1877) of the rocks of Iguana Creek, Freestone Creek, and north from there, are almost entirely confined to the beds at the base of the series, and he merely mentions that above the red beds with intercalated lavas there must be a further great thickness of Upper Palaeozoic rocks. The fine natural sections afforded by the escarpment at the edge of the series afford so ready a means of observation that the importance of the beds that crop out there seems to have been overestimated. Murray, however, traversed the central part of the belt, and his remarks (1878) are illuminating, for he found that the "felstones, porphyries, etc., continue among the lower beds of the series" in the south, while the general sequence seems to be "immediately on the Silurian coarse conglomerate or breccio-conglomerate, then melaphyres and felsites, and then the bulk of the sedimentary sandstones, shales, and conglomerates".

Further north at Mt. Wellington, the same relations hold, Theile (1907) writing that "the igneous rocks of the series appear to be invariably found at or near the base of the series", while at Mt. Timbertop some fifteen miles south-east of Mansfield the same author describes a thick acid lava flow at the base of the red beds. Now the plant remains from Iguana Creek and the new fish remains from Freestone Creek also occur somewhere within the basal series, being part of the formation stretching from Snowy Bluff round the edge of the belt to the Avon River, and thence north to Ben Cruachan, Mt. Wellington, and even further. And these fossils are Upper Devonian. Therefore the conclusion is reached that the basal beds of the Upper Palaeozoic belt, characterized by the presence of thick felsite flows (up to 2,000 feet) with overlying melaphyres are Upper Devonian; but this does not include the masses of red beds without important intercalated lavas that overlie the basal beds.

The evidence for the age of these beds consists of the Lower Carboniferous Mansfield fishes associated with *Lepidodendron mansfieldense* McCoy: a fish scale identified (with doubt) by Mr. Chapman (1907) as the Carboniferous genus *Strepsodus* found at Mansfield from the Mt. Wellington area: *Lepidodendra* from the

same locality (specimens in the National Museum, Melbourne, are certainly not *L. australe* McCoy) : and *L. australe* McCoy, of no stratigraphic value, from the Avon River. Teale, who worked both at Mansfield and further south, says (1920) that the evidence of the separation of the Mt. Wellington from the Mansfield sediments is inconclusive, so that it seems reasonable to assume that in the overlying red beds of the belt of Upper Palaeozoic rocks we are dealing with a Lower Carboniferous series.

To summarize, it may with some justification be assumed that there are exhibited in eastern Victoria both an Upper Devonian and a Lower Carboniferous series of deposits, that the two are pratically co-extensive, and are not separated by any marked angular unconformity. The Devonian rocks are characterized by thick intercalated flows of felstone with overlying melaphyres, while the deposits of the younger epoch consist predominantly of sedimentary formations, with perhaps a few thin melaphyres near the base ; each series contains its appropriate fossil remains, both flora and fauna. It should be understood, of course, that without confirmatory research over practically the whole belt, the above suggestions must remain merely tentative.

4. Correlation with other Areas.

(*a*) *The Central Victorian Dacites.*

We concluded above that the special feature of the Upper Devonian rocks in the eastern Upper Palaeozoic belt was the evidence of intense volcanic activity they present. Even before the discovery of *Bothriolepis gippslandiensis* Hills in the east, the rocks of Taggerty had been compared in detail with the basal series of Mt. Wellington (Hills, 1929), and now it is even more apparent that we have to deal with similar series in both localities. It remains to seek a genetic connection between the igneous rocks, and to explain the position of the dacites, the equivalents of which do not seem to be present in the eastern belt. It may be that they will be found to be coeval with the melaphyres, or perhaps to be represented by a disconformity at the top of the Upper Devonian in the eastern districts.

(*b*) *The Grampians Sandstones.*

Finally, we must take into consideration the sandstones which constitute the Grampian Mountains in the western part of the state. Until a few years ago these had yielded no fossils, but even the earliest workers had recognized their general connection with the eastern Upper Palaeozoic belt, Selwyn (1866) considering that the two areas are the limbs of a great denuded anticline over central Victoria. In 1913, however, Mr. Chapman was able to determine their age as Lower Carboniferous on the basis of fish spines and a Lingula (*Physonemus micracanthus* Chapm., *P. attenuatus* Davis, *Lingula squamiformis* Phillips, var. *borungensis* Chapm.).

If lithological features alone were considered, these sandstones would be correlated with the upper, sedimentary series of the eastern Upper Palaeozoic belt, and would be separated from the basal, mainly igneous series, whose equivalents might be, and were sought in the acid lavas of Taggerty. When it is found that all the available palaeontological evidence points to exactly the same result, such correlation may be regarded as justified.

Conclusion.

Finally, I should like to thank those very numerous people whose help was so often and freely given during the progress of the research. A complete acknowledgement is impossible, but I must mention especially the staff of the Natural History Museum at South Kensington—Dr. W. D. Lang for permission to work in the Museum, Dr. E. I. White who discussed some of the fossils with me, and many others. Professor D. M. S. Watson kindly read through the palaeontological section and discussed many points, also allowing me the use of his unique collection, while Professors W. W. Watts and P. G. H. Boswell advised me as to points of presentation. Reference has already been made to the goodness of Mr. W. Baragwanath in lending the material from Freestone Creek in the Survey Museum, and in this connection I should also like to thank Mr. J. A. Kershaw, Curator of the National Museum, Melbourne, for lending me further material from the same locality. I owe the opportunity of conducting the work in London to the granting by the Commissioners for the Exhibition of 1851 of an Overseas Studentship.

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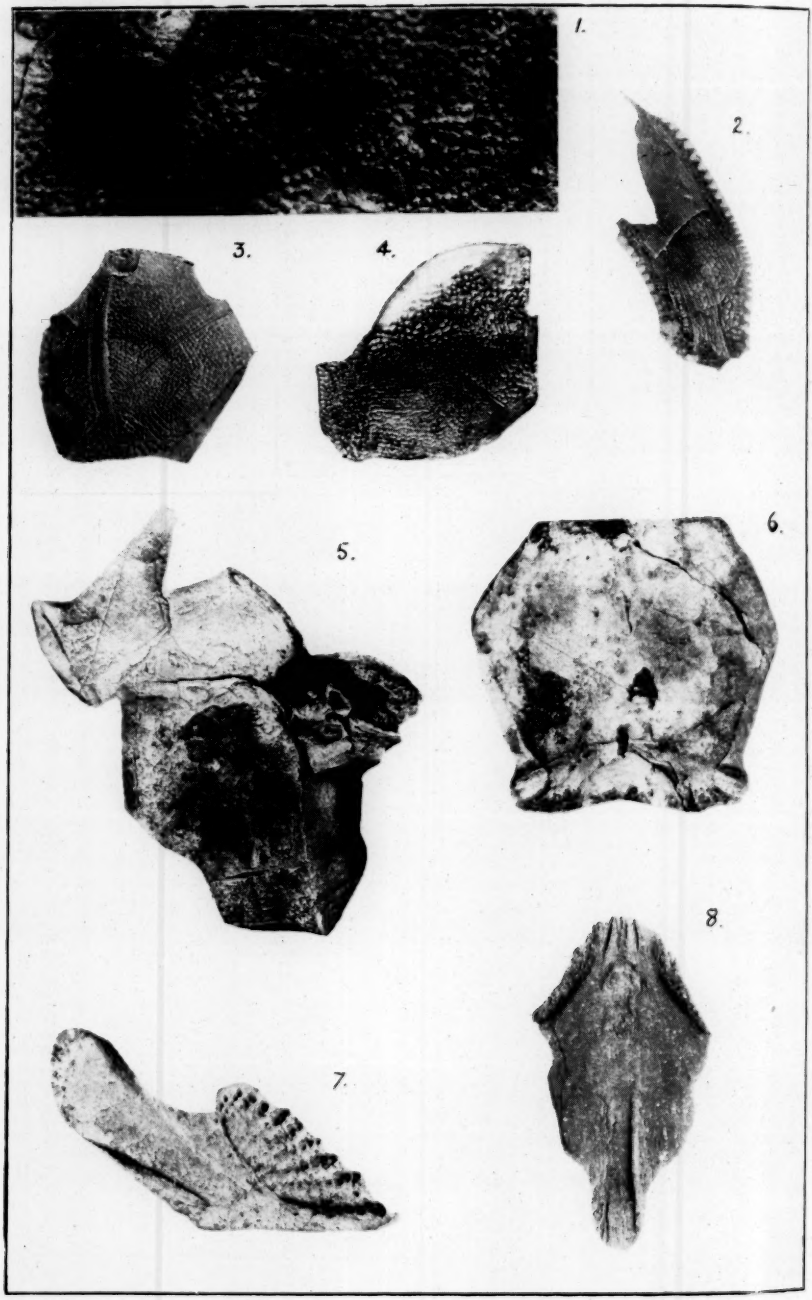

UPPER DEVONIAN FISHES, TAGGERTY, VICTORIA.

To face p. 231.]

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EXPLANATION OF PLATE XI.

Upper Devonian Fishes, Taggerty, Victoria.

FIG.
1.—*Bothriolepis gippslandiensis* Hills. Portion of the ornament of a large anterior ventro-lateral plate (mould) showing the gradation between reticulate and tuberculate ornament on the one specimen. × 2.
2.—*B. gippslandiensis* Hills. Ventral internal and external marginals of the right appendage. × 3/2.
3.—*B. gippslandiensis* Hills. Plasticine squeeze of a left posterior dorso-lateral plate, incomplete. × 1.
4.—*B. gippslandiensis* Hills. Mould of the right side of an anterior median dorsal plate. × 1.
5.—*B. gippslandiensis* Hills. Internal cast of a left anterior ventro-lateral plate with part of the lateral appendage, and the posterior part of the right anterior ventro-lateral, displaced anteriorly. × 1.
6.—*B. Gippslandiensis* Hills. Internal cast of a large anterior median dorsal plate. × 1.
7.—*Dipterus microsoma* (Hills). Mould of the buccal surface of the left dental plate and pterygoid. × 2.
8.—*D. microsoma* (Hills). Mould of the buccal surface of a parasphenoid, the shaft incomplete. × 2.

Note.—Although some of the figures are photographs of moulds, owing to an optical illusion it is possible that they may appear to the observer as the actual specimen would. This applies particularly to Nos. 1, 4, and 7.

On a Dolerite in the Dutch Carboniferous.

By S. Tomkieff (Armstrong College, Newcastle-on-Tyne) and P. Tesch (Geological Survey, Holland).

In 1928 Dr. P. Tesch published a note on the occurrence of an igneous rock in Dutch Coal-measures (1).[1] As this is the first occurrence of an igneous rock in Holland, the present authors have decided to publish a more detailed petrographical description of the rock, together with an attempt to correlate it with similar rocks in Great Britain and Germany.

Nearly the whole of the Carboniferous in Holland is found under a thick cover of Mesozoic and Tertiary deposits. As far down as the workings and borings have penetrated, strata corresponding to the English Lower and Middle Coal-measures have been found present, and apparently the Dutch Coal-measures belong to the same area of deposition as the English eastern coal basins—on one side, and the Westfalian basin—on the other side.

[1] Figures refer to the list of references at the end of the paper.

The rock described here has been discovered in a boring in the eastern part of the province of Gelderland, near the German frontier (Munster basin, Westfalia), between the villages of Winterswijk and Lichtenvoorde. The locality is often called Corle or Korle.

The general section of this boring is as follows :—

Surface : 28 meters O.D.

0 to	30 m.	below surface.	Pleistocene deposits.
30 ,,	77 m.	,, ,,	Tertiary (Oligocene).
77 ,,	490 m.	,, ,,	Trias (Bunter).
490 ,,	691 m.	,, ,,	Upper Permian (mainly anhydrite and rock salt).
691 ,,	1,284 m.	,, ,,	Middle Coal-measures.

The exact occurrence of the dolerite in question is as follows :—

— to	970 m.	Shale with plant roots (*Stigmaria*). Horizontal.
970 ,,	972 m.	Light coloured marginal zone (" White trap "), with calcite veins.
972 ,,	981 m.	Fresh dolerite.
981 ,,	983 m.	Light coloured marginal zone (" White trap "), with calcite veins.
983 ,,	—	Shale, similar to that of the roof.

The shale shows metamorphic effects only at the actual contact with the intrusion.

The total thickness of the dolerite as observed in the borehole is 13 metres (including the altered marginal zones).

This great apparent thickness of the dolerite may indicate that we are here dealing with a dyke rather than a sill, but in the absence of any additional evidence the question as to the form of the intrusion must remain unsolved.

The white trap, apparently a marginal alteration-facies of the dolerite, is a whitish compact rock of Sp. Gr. 2·725, and of a slightly finer grain than the fresh dolerite. Under the microscope it shows a characteristic texture of a dolerite, but with all the constituent minerals completely altered. Felspar is saussuritized with a development of a fibrous mineral of low refractive index and low birefringence, the precise determination of which proved to be difficult. Calcite is present in considerable amount. The ferromagnesian constituents are completely altered to chlorite and calcite. Secondary light coloured fibrous chlorite and chalcedony are also present.

The unaltered rock is a grey medium-grained dolerite. As felspar is the dominant constituent in this type of rock, the best index of grain-size of the rock is the average size of felspar laths. For the purpose of comparison, some of the rocks subsequently to be discussed, as well as the rock in question, were measured on the

Shand stage in respect to the average size of felspar laths, with the following results :—

Dolerite, Holland . .	0·57 mm.
Whin Sill, Crook boring .	0·42 mm.
Whin Sill, Swinburn . .	0·32 mm.
Tholeiite, Tholei . . .	0·20 mm.

The specific gravity of the rock at (4° C.) is 2·801.

Under the microscope it has a remarkable resemblance to the medium-grained variety of the Whin Sill of the North of England, with the sole exception that the chloritic mesostasis is much more abundant, occurring in patches and thus presenting a typical intersertal texture characteristic of tholeiites.

The dominant mineral is felspar, as a rule fresh, but in contact with viriditic mesostasis often turbid and chloritized. The laths are graded in size, and few microphenocrysts are present. The twinning is albitic and the crystals are often progressively zoned with basic central portion. According to the symmetrical extinction and refractive index the felspar has an average composition of $Ab_{45}An_{55}$.

The ferromagnesian portion is represented by a brown augite and chlorite. The augite is non-pleochroic, with an oblique extinction, generally fresh, but in places chloritized. It is in ophitic or subophitic relationship to the felspar and distributed in large patches, alternating with similar patches of chloritic mesostasis.

The presence of rhombic pyroxene is suggested by a few observed hypidiomorphic crystals with straight extinction, almost completely altered to bastite.

The mesostasis is a confused mass (generally described under the very indefinite name of viridite) of fibrous chlorite, light-green in colour, intimately mixed with an acid felspathic material. Besides viriditic chlorite, orange, brown, green, microspherulitic colloform chlorite is also found. These varieties of chlorite may be safely assigned to chlorophaeite. Clear patches of quartz are often observed among the chloritic mesostasis. Calcite is also present. Small flakes of biotite and long laths of pleochroic hornblende are also observed in the mesostasis.

Iron oxides (titaniferous magnetite, as suggested by alteration to leucoxene in places) are found in medium-sized grains and irregular patches, often moulded on felspar laths and cementing cracks in felspar and pyroxene crystals, and are probably in part of a late magmatic or secondary nature.

Pyrite is rather abundant in the microsections studied. It has a tendency to segregate in definite areas, and as in certain contact varieties of the Whin Sill appears in the form of spongy masses filling the space between other crystals and cracks.

Apatite in the form of slender needles is present in a small amount.

The quantitative mineralogical composition of the dolerite from

Holland, together with some British and German dolerites and tholeiites for comparison, is given on the following table :—

TABLE I.

	1		2		3	4	5	6
	a	*b*	*a*	*b*				
Olivine . .	—	—	—	—	5·30	4·05	—	—
Felspar . .	40·50	47·10	51·28	37·21	57·70	31·40	33·7	46–48
Pyroxene . .	18·55	21·55	34·05	22·22	22·80	36·50	26·1	12–15
Chlorite, etc. .	20·85	24·25	4·55	9·20	11·20	28·05	6·9	30
Glass . . .	—	—	—	—	—	—	18·0	
Quartz. . .	—	—	—	2·47	—	—	—	—
Micropegmatite .	—	—	—	15·86	—	—	—	—
Apatite . .	—	—	—	—	—	—	1·0	—
Iron Oxides . .	6·10	7·10	10·12	12·82	3·00	—	14·3	—
Iron Pyrites .	14·00	—	—	0·22	—	—	—	—

1. (*a*) Dolerite, Holland.
   (*b*) Same, recalculated without the pyrite.
2. (*a*) Whin Sill, Medium-grained (average).
   (*b*) ,, Coarse-grained (,,).
3. Tholeiite. Tholei, Saar-Nahe district, Germany.
4. ,, Tertiary dyke, Kielder Head, Northumberland.
5. ,, Dalmeny, Scotland (F. Walker).
6. ,, Dalmahoy, Scotland (R. Campbell and J. W. Lunn).

All measurements were carried out on the Shand stage under 1 in. objective, and then recalculated into weight percentages.

In all its aspects, except that of a higher development of chloritic mesostasis (although certain coarse-grained varieties of the Whin Sill may contain up to 10 per cent of mesostasis) and of a high percentage of pyrite (probably purely accidental and determined by pneumatolytic action from the surrounding strata), the dolerite from Holland strikingly resembles the rock of the Whin Sill of the North of England. A tholeiitic phase as such is certainly not typically developed in the Whin Sill proper, but as recently shown by F. Walker (2), it is present in the quartz-dolerites of Scotland, in rocks, in respect both of age and composition identical with the Whin Sill.

Tholeiites are well represented in the suite of Tertiary dykes in Scotland and the North of England. They range from olivine-tholeiites to more acid varieties approaching andesites in chemical composition (3). A typical Tertiary tholeiite is given in Fig. 1, and its mineral composition in Table I. But as was first pointed out by G. Mockler (4), the most striking difference existing between the Tertiary and Carboniferous rocks in Northumberland is in the relative proportion between the felspars and the pyroxene. Tertiary basalts are as a rule characterized by the predominance of pyroxene

over the felspar, while in the Carboniferous basalts and dolerites this relation is reversed. In this particular respect the dolerite from Holland comes into line with the British Carboniferous rocks.

Taking the tholeiite from Tholei, Saar-Nahe district, Germany, as defined by Steininger and later studied by Lossen, as the typical representative of this type of rocks, together with the more extensive application of this term by later authors, we can define it as a basalt or dolerite with a pronounced intersertal texture in respect of glassy or chloritic mesostasis.

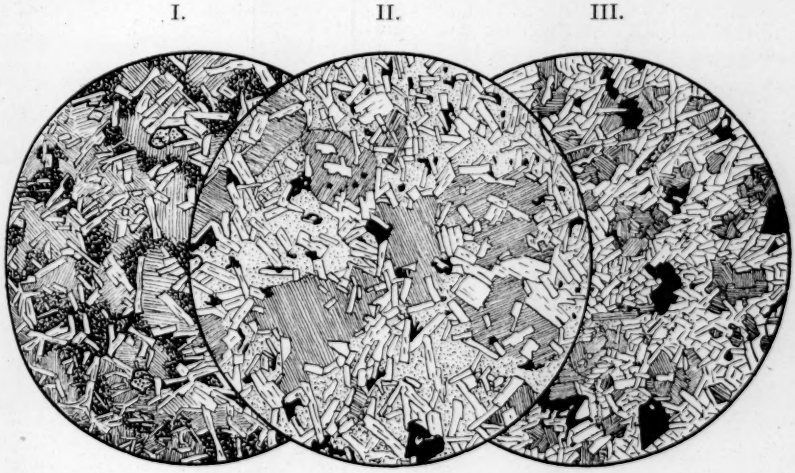

FIG. 1.

Magnification × 8½ . (Diameter, 6·3 mm.)

Dark stippled areas	Dark chloritic mesostasis.
Light stippled areas	Light chloritic mesostasis.
Parallel shading	Pyroxene.
Unshaded	Felspar.
Black	Iron Ore.
In I, heavy stippled areas with dark border	Olivine.

I. Tholeiite, Black Needle Burn, Kielder Head, Northumberland. Tertiary basaltic dyke. Ophitic pyroxene alternating with areas of dark chloritic mesostasis.
II. Dolerite. Gelderland, Holland.
III. Dolerite. Whin Sill, Swinburn, Northumberland.

According to this definition, the dolerite from Holland is undoubtedly a tholeiite, but as it resembles a typical rock of the quartz-dolerite type we may call it a tholeiitic variety of the quartz-dolerite magma.

The development of quartz in the mesostasis of this rock may be compared with the development of quartz in the mesostasis of the coarser varieties of the Whin Sill, belonging to the later stages of magmatic consolidation (5).

On the other hand, it bears also certain resemblances to the tholeiites of the Dalmeny type, as described by Walker and also to the Dalmahoy type (6), although the latter belong to a slightly different type of magma, and it is also of an earlier period of volcanic activity.

In any case, with the data in hand we may safely say that of all the rocks of similar composition, the dolerite from Holland is nearer to that of quartz-dolerite type, and from that we may infer that it belongs to the same period of igneous activity. The igneous rocks of the Saar-Nahe district represented by a suite ranging from dolerites and basalts (magma similar to that of Whin Sill), to acid quartz-porphyries, are found in the lower Permian, and as they are accompanied by analogous extrusives, so they must be relegated to the Lower Permian igneous activity. A. Holmes (7) considers that the intrusion of the Whin Sill took place following the Asturian phase of folding (post-Westfalian), while the Saar-Nahe rocks can be definitely placed in the Saalian phase (post-Lower Rothliegende). Without attempting to correlate the igneous activities in these two separated regions, we may assume that the late Hercynian movements (Permo-Carboniferous) were generally accompanied by a cycle of igneous activity resulting in intrusions of quartz-dolerite type of magma, of which the dolerite from Holland is a representative.

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REVIEWS.

WELLS AND SPRINGS OF WORCESTERSHIRE. By L. RICHARDSON, Mem. Geol. Survey. pp. v + 219, with 1 plate and 3 text-figs. 1930. Price 4*s*.

THIS memoir is written on the now well-known standard plan, which has proved so useful in the case of many other counties in recent years. It is enriched by a very large number of analyses made by the County Analyst, Mr. C. C. Duncan and a contribution on rainfall by Mr. B. Brotherton. In connection with Worcestershire and its water supply the thoughts of most readers will naturally turn first to the famous Malvern waters, and it is curious to find that apart from these famous springs, the Malvern area has actually had in the past grave difficulties to contend with in providing an adequate supply for general purposes, owing to the concentration of population on a high, narrow ridge, the Malvern Hills, with a very inadequate gathering ground, and specially active evaporation, owing to its isolated position and geological structure: only a very small proportion of the rather low rainfall is available as springs. The rest of the county is less spectacular from this point of view, as plenty of water is generally available in the Trias, though the Lias area in the south-east is not well supplied, being mostly clay: the water from various limestones, in limited quantity, is often very hard.

OBITUARY.

Thomas Crosbee Cantrill, B.Sc., F.G.S.

1867–1931.

By the death of Thomas Crosbee Cantrill on 3rd April, 1931, the sciences of geology and archaeology have alike suffered a serious loss. Born on the 20th November, 1867, he was educated at the Edward VI Grammar School, at Stonebridge, and afterwards at Mason's College, Birmingham, graduating B.Sc. in 1891. During a brief scholastic career he investigated with success the structure of the Forest of Wyre Coalfield, for which work he was awarded the Heslop Gold Medal in 1895, and in 1896 joined the staff of the Geological Survey. For fourteen years he served as geologist in the investigation of the South Wales Coalfield, and, in co-operation with the late Sir Aubrey Strahan and others, was part author of nine memoirs and one-inch maps of the coalfield.

In 1910, on the completion of this survey, he was transferred to the Midlands and was occupied in the Lichfield area until his appointment as District Geologist in 1914.

During the war he prepared several of the *Special Reports on Mineral Resources* and in 1919 resumed normal field-work in North

Wales and the West Midlands. In 1921 his activities were interrupted by a breakdown in health from which he recovered sufficiently to overtake the arrears of publication due to the war. The concentrated effort involved in the completion of this task allowed him little opportunity for rest or recreation.

He retired in November, 1927, to his native county of Worcestershire, and devoted his well-earned leisure to the study of local archaeology; a subject in which he had always evinced a great interest. He contributed sever alpapers to *Archaeologia Cambrensis* and other antiquarian journals; especially on the subject of prehistoric cooking places.

Cantrill was always a keen geologist, a good observer, and a most painstaking and accurate recorder of facts, both in his published work and in his conscientious and detailed mapping. He endeared himself to his colleagues, as indeed to all who knew him well, by his kindly and courteous nature and, though of a somewhat retiring disposition, was well known to many as a man of wide experience and sound judgment as a coalfield geologist. His *Handbook on Coal Mining* is still a readable and reliable guide to the subject. His loss will be keenly felt by all those who had the good fortune to be counted among the number of his friends.

R. W. P.

CORRESPONDENCE.

LARGER FORAMINIFERA FROM THE TERTIARY OF SOMALILAND.

Sir,—Since Mr. Brighton could answer my letter (in your issue for April), before it was published, while I only see his reply after it appears in print, I hope that you will allow me to say a few words more.

What I protested against was Messrs. Nuttall and Brighton's sweeping statement (backed by a very one-sided selection of data) that I had had "no justification" for referring the Kohat Shale to the Laki. I would therefore point out that Mr. Brighton has now had to admit that "characteristically Lower Eocene forms" (hitherto totally ignored by himself and his colleague) *had* been reported throughout the Kohat Shale; and whatever else he may say in his letter (apparently trying to defend the statement against which I protest) he concludes by admitting that, at present, the age of the Kohat Shale fauna "must remain in doubt".

I think this bears out my protest. Mr. Brighton's admissions show that I did have some justification for referring the Kohat Shale to the uppermost Laki.

L. M. Davies.

Leith Fort,
Edinburgh.
11*th April*, 1931.

GEOLOGICAL SURVEYS IN S.E. ASIA.

SIR,—I have just received a copy of *Methods in Geological Surveying* by Dr. Edward Greenly and Dr. Howell Williams. On pp. 103–18 the authors give a list of countries with geological surveys, but no mention is made of the Federated Malay States or Malaya. The completed geological map of Malaya was published by the Survey Department last year. In 1926 a "Progress Map" was published. A geological map of Kinta was published in 1927. Other maps of South Perak, Selangor, Negri Sembilan, and Ulu Pahang have been published.

On p. 119, paragraph 7, the authors state that practically the whole of the East Indian Archipelago is untouched as far as geological surveying is concerned. This shows that the authors have ignored the work of Dutch geologists in the Netherlands East Indies as completely as they have ignored that of my Department. One of the finest geological maps ever produced is that of Java and Madoera, by Verbeek and Fennema, published in 1896. This is in twenty-six sheets on the scale 1 : 200,000. The Netherlands Indies Geological Survey is now publishing a Geological Atlas of the whole of the Dutch East Indies, sheet by sheet. Their Folio 11 (eleven) contains the Malay Peninsula, and I was invited to supply a geological map of the Peninsula up-to-date. This was published in 1925 on the scale 1 : 1,000,000. I have in my office two sheets of their Atlas joined together, that containing the Malay Peninsula and the adjoining sheet containing a large part of Sumatra, the Lingga Archipelago, and Banka. Reference to the "Jaarboek van het Mijnwezen" will show that many other geological maps of parts of the Dutch East Indies have been published. The authors' statement that practically the whole of extra-Indian continental Asia is untouched will also interest the French geologists who are working in Indo-China. In 1929 Monsieur F. Blondel, then Director of their survey, suggested at the Fourth Pacific Science Congress that geologists should co-operate in producing a small-scale geological map of countries in Asia near the Pacific Ocean. It was agreed that British Malaya, the Netherlands Indies, and French Indo-China could produce such a map, but that as Siam has no geological survey, Indo-China and Malaya cannot yet "join up".

J. B. SCRIVENOR,
Director, Geological Survey, Federated Malay States.

GEOLOGICAL SURVEY DEPARTMENT,
BATU GAJAH,
FEDERATED MALAY STATES.
24*th February*, 1931.